

**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>7</sup> :</b> <b>C12N 15/11, C07K 14/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 00/46365</b> <b>(43) International Publication Date:</b> 10 August 2000 (10.08.00)
<b>(21) International Application Number:</b> PCT/US00/02413 <b>(22) International Filing Date:</b> 2 February 2000 (02.02.00) <b>(30) Priority Data:</b> 60/118,526 2 February 1999 (02.02.99) US <b>(71) Applicants:</b> VIRGINIA COMMONWEALTH UNIVERSITY [US/US]; 1101 E. Marshall Street, Richmond, VA 23298 (US). BIOCACHE PHARMACEUTICALS, L.L.C. [US/US]; 800 E. Leigh Street, Richmond, VA 23227 (US). <b>(72) Inventors:</b> COLEMAN, Timothy, P.; 22 Holmes Street, Rehoboth, MA 02769 (US). PETERSON, Darrell, L.; 4345 Roundhill Drive, Chesterfield, VA 23832 (US). <b>(74) Agent:</b> WHITHAM, Michael, E.; Whitham, Curtis & Whitham, 11800 Sunrise Valley Drive, Suite 900, Reston, VA 20191 (US).	<b>(81) Designated States:</b> AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GR, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
<b>(54) Title:</b> ADVANCED ANTIGEN PRESENTATION PLATFORM  <b>(57) Abstract</b>  The present invention provides particles for the presentation of haptens for the purpose of eliciting an immune response. The amino acid sequences of the monomers which make up the particles are derived from duck hepatitis B virus core protein. The particles may also deliver nucleic acids. The nucleic acids may be delivered for the purpose of enhancing an immune response, or for other purposes such as gene therapy.		

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## ADVANCED ANTIGEN PRESENTATION PLATFORM

### DESCRIPTION

#### BACKGROUND OF THE INVENTION

##### Field of the Invention

5           The invention relates to the development of vaccines and specifically to the development of an improved method for antigen presentation. The invention further relates to the delivery of nucleic acids to cells via a particle.

##### *Background Description*

10           The aim of all vaccinations is to induce specific immunity that prevents microbial invasion, eliminates microbes that have already invaded the host, or neutralizes microbial toxins. Unfortunately, the development of effective protein subunit or peptide vaccines against intracellular pathogens has been hindered by major technological and conceptual inadequacies.

15           One such inadequacy is the inability to elicit a strong TH1 immune response. The response of the immune system to an antigen during vaccination can be somewhat variable depending on the size and composition of the disease specific antigen, and the particular adjuvant used to enhance the immune response. Potential responses include TH1, TH2 or mixed (TH1/TH2) responses.

20           Cytokine profiles determine T cell regulatory and effector functions in immune responses. Cytokines play a role in directing the T cell response. Helper (CD4+) T cells orchestrate the immune response of mammals through production of soluble factors that act on other immune system cells, including other T cells. Most mature CD4+ T helper cells express one of  
25           two cytokine profiles: TH1 or TH2. TH1 cells secrete IL-2, IL-3, IFN- $\gamma$ , TNF- $\beta$ , GM-CSF and high levels of TNF- $\alpha$ . TH2 cells express IL-3, IL-4, IL-5, IL-6, IL-9, IL-10, IL-13, GM-CSF and low levels of TNF- $\alpha$ . The TH1 subset promotes delayed-type hypersensitivity, cell-mediated immunity, and

immunoglobulin class switching to IgG2. The TH2 subset induces humoral immunity by activating B cells, promoting antibody production, and inducing class switching to IgG, and IgE.

5 Several factors have been shown to influence commitment to TH1 or TH2 profiles. The best characterized regulators are cytokines. IL-12 and IFN- $\gamma$  are positive TH1 and negative TH2 regulators. IL-12 promotes IFN- $\gamma$  production, and IFN- $\gamma$  provides positive feedback for IL-12. IL-4 and IL-10 appear to be required for the establishment of the TH2 cytokine profile and to down-regulate TH1 cytokine production; the effects of IL-4  
10 are in some cases dominant over those of IL-12. IL-13 was shown to inhibit expression of inflammatory cytokines, including IL-12 and TNF- $\alpha$  by LPS-induced monocytes, in a way similar to IL-4. The IL-12 p40 homodimer binds to the IL-12 receptor and antagonizes IL-12 biological activity; thus it blocks the pro-TH1 effects of IL-12.

15 A TH1 response is marked by mobilization of macrophages, B-cells antibody producing cells, professional antigen presenting cells (APCs), and cytotoxic T lymphocytes (CTL) for the phagocytic elimination of microbes. Further, a TH1 response induces the expression of IFN- $\gamma$ . IFN- $\gamma$  promotes the switching of B cells to isotypes such as IgG2 which fixes complement  
20 and promotes phagocytosis by macrophages. IFN- $\gamma$  also activates the antimicrobial functions of macrophages. A TH1 immune response thus induces phagocyte-dependent host reactions that are important for the elimination of intracellular microbes, and it is therefore highly desirable for a vaccine to elicit a strong TH1 response.

25 Several studies have reported that the cytokine IL-12 plays a critical role in inducing antiviral effects *in vivo* by promoting the TH1-type immune response. IL-12 is mainly produced by activated antigen presenting cells (APCs) including macrophages, dendritic cells, and B cells, and is reported to augment antibody, CD4<sup>+</sup>, and CTL responses. IL-12 induces the  
30 maturation of type-1 TH cells into IFN- $\gamma$  producing cells, promotes natural killer (NK) activity, and enhances CTL maturation. It is a heterodynamic cytokine consisting of two subunits, p35 and p40. The p35 subunit is

constitutively expressed, while the p40 subunit is expressed only upon APC activation. It is therefore highly desirable for a vaccine to elicit the production of IL-12.

Protein subunit or peptide vaccines are often not immunologically  
5 active by themselves and must be administered with an adjuvant. Aluminum hydroxide (alum) is currently the only adjuvant approved for human use. An important disadvantage of alum is that it induces a TH2- rather than a TH1-type immune response, and this may interfere with induction of CTL. Indeed, in mice immunized with recombinant Hepatitis B surface antigen  
10 (HBsAg), the addition of alum selectively blocked activation of CD8+ CTL (Schirmbeck et al., 1994). Although not essential for protective immunity against HBV, CTL may nevertheless play an important role.

The use of alum has been linked to TH2-type diseases. The much higher prevalence of asthma (a TH2-type disease) in more highly developed  
15 nations may be linked to the high hygiene level and rapid treatment of childhood infections (Cookson and Moffatt, 1997). Early exposure to bacterial DNA pushes the immune system away from TH2- and towards a TH1-type response and this may account for the lower incidence of asthma in less developed countries, where there is a much higher frequency of upper  
20 respiratory infections during childhood. It would be an advantage to have available pediatric vaccines capable of re-establishing a TH1-type response, thereby reducing the incidence of asthma.

In order to elicit a strong TH1 response by an antigen which is deposited in the extracellular fluid (which is the case with most vaccines)  
25 very high concentrations of the antigen are necessary. This cannot be accomplished in a safe and efficacious manner. However, one solution to the problem is to deliver disease-specific antigens on the surface of a particle. Both macrophages and dendritic cells internalize particles into large vacuoles where exogenous antigens can be transferred to both the class I and class II  
30 presentation pathways. This exogenous class I presentation pathway is of considerable interest for vaccine development because it provides a means of eliciting CTL immunity with antigens that are deposited into the extracellular

fluid. It has been demonstrated that when exogenous antigens are particulate in nature, they are presented 1,000 to 10,000-fold more efficiently than soluble antigens in both the class I and class II pathways (Harris et al., 1992; Griffiths et al., 1993; Schodel et al., 1994; Schirmbeck et al., 1995; and Raychaudhuri and Rock, 1998). One example of the use of particles to carry antigens is that of the human hepatitis B viral core antigen (HBcAg). It has been shown that human HBcAg is capable of serving as an effective carrier for foreign epitopes which have been chemically coupled to, or genetically engineered into, the protein sequence at several selected sites (Milich, 1990; Schodel et al., 1992; Schodel et al., 1993; Schodel et al., 1994; Milich et al., 1995). Also, see, for example, the following United States Patents to Thornton et al.: 4,882,145; 4,882,145, and 5,143,726, which are incorporated herein by reference. The patents are directed toward the use of fusion proteins comprised of T cell stimulating regions of the human Hepatitis B viral (HBV) nucleocapsid protein linked to a polypeptide immunogen. However, one serious drawback to the use of human HBcAg as a vaccine carrier is that antibodies against HBcAg itself (anti-HBc) also develop in recipients of the vaccine. This is a problem because the detection of HBV infection in humans, and in blood which has been donated for use in transfusions, is by screening for anti-HBc in the blood. Therefore, widespread use of a vaccine based on human HBcAg would compromise the currently used hepatitis B screening system. The use of hepatitis B-based particles from some other species (e.g. woodchuck) would also pose the same problem since they are crossreactive with human HBcAg. It is estimated that approximately 500 million people are infected with HBV worldwide. In these individuals, the administration of a vaccine based on human HBcAg would be fruitless, since their immune system would likely attack and destroy the vaccine particles before they could exert their immunizing effect. It would therefore be advantageous to have available a particulate vaccine carrier which did not interfere with current HBV screening protocols.

Another major inadequacy of current vaccines is the inability to

produce vehicles to deliver haptens that are effective in stimulating a specific immune response to "quasispecies" of the invading microbe. Quasispecies are progeny of the original microbe that develop during infection. The genetic structure of quasispecies has been altered by mutation, allowing these structurally similar microbes to escape elimination by the immune system and maintain the pathological condition. It would thus also be highly desirable to develop a hapten vehicle for use in vaccines that was capable of eliciting a protective response against a wide variety of structurally similar haptens such as those exhibited by genetically hypervariable microbes (e.g. viruses). Such a hapten vehicle could stimulate an immune response against the targeted microbe and quasispecies produced during infection.

#### SUMMARY OF THE INVENTION

The present invention provides a composition comprised of a plurality of nucleocapsid protein monomers, the primary sequences of which are derived from duck hepatitis B virus, wherein said plurality of monomers are assembled to form a particle. The monomers may further include a first and second hapten, as well as multiple haptens, depending on the use of the particle. The particles may further include nucleic acids. Those nucleic acids may have but are not limited to sequences corresponding to SEQ IDs number 3-19.

The haptens may be associated with a disease condition caused by an agent selected from the group consisting of: single single stranded DNA viruses, double stranded DNA viruses, single stranded RNA viruses, double stranded RNA viruses, intracellular parasites, fungi, bacteria, and cancer.

The invention further comprises a method of delivering nucleic acids to a subject in need thereof by administering a composition comprised of a plurality of nucleocapsid protein monomers assembled in the form of a particle where the particle incorporates the desired nucleic acid sequence.

The present invention also provides a method for making particles, which method comprises the steps of: providing a composition comprised of

a plurality of nucleocapsid protein monomers, the primary sequences of which are derived from duck hepatitis B virus, wherein said plurality of monomers are assembled to form a particle, exposing said particle to a charged agent to disassemble the particle and allow for mixing in nucleic acids or other nucleocapsid monomers that include different haptens, and removing said charged agent; the removal of the charged agent allows the monomers to reassemble. Further steps may be included in the method, such as removing unwanted nucleic acids and adding desired nucleic acids. The charged agent may be a divalent cation selected from the group consisting of:  $Mg^{+2}$ ,  $Zn^{+2}$ ,  $Ba^{+2}$ ,  $Sr^{+2}$ ,  $Ca^{+2}$  and  $Pb^{+2}$ .

### BRIEF DESCRIPTION OF THE DRAWINGS

**Figure 1.** Amino acid sequence of duck HbcAg.

**Figure 2.** Nucleic acid sequence of duck HbcAg.

**Figure 3.** Illustration of extrinsic mosaic recombinant duck HBcAg particles.

**Figures 4A and 4B.** Analysis of specific RNAs in J774A.1 macrophage cells after exposure to recombinant duck HBcAg particles (4A) or recombinant t-duck HBcAg particles (4B). RNA was detected by reverse transcriptase polymerase chain reaction (RT-PCR) and visualized by agarose gel electrophoresis.

**Figures 5A and 5B.** Concentration of IL-12 in the culture medium (5A) or the cell extract (5B) of J774A.1 macrophage cells following treatment with recombinant duck HBcAg particles or recombinant t-duck HBcAg particles for 72 hours.



**Figure 6.** Concentration of IL-12 in the culture medium of bone marrow-derived dendritic cells from BALB/C and B10 mice following treatment with recombinant duck HBcAg particles for 24 hours.

**Figure 7A, 7B, 7C, 7D and 7E.** Flow cytometry analysis of cell surface antigen expression in J774A.1 macrophage cells after treatment with recombinant duck HBcAg particles. 7A: CD86; 7B: MHC I; 7C: MHC II; 7D: Ly-6A/E; 7E: Ly-6C. Arrows: 1, shaded area: isotype control; 2, solid line: non-treated control; 3, dotted line: treated with 10 $\mu$ g recombinant duck HBcAg particles.

**Figure 8A and 8B.** Total IgG titer for duck HBcAg *in vivo*. 8A: B10 mice. 8B: BALB/C mice.

**Figure 9.** IgG isotype titers for duck HBcAg in B10 and BALB/C mice.

**Figure 10A, 10B, 10C and 10D.** Flow cytometry analysis of cell surface antigen expression in spleenocytes following re-stimulation with 1 $\mu$ g duck HBcAg *in vitro* for 24 hours. 10A: CD86; 10B: Ly-6C; 10C: CD4+; 10D: CD8+. Arrows: 1, immunized with 0  $\mu$ g of duck HBcAg. 2, immunized with 1  $\mu$ g of duck HBcAg. 3, immunized with 10  $\mu$ g of duck HBcAg.

**Figure 11A and 11B.** Comparison of crossreactivity of woodchuck with duck and human antibodies (11A) and crossreactivity of human with duck and woodchuck antibodies (11B).

**Figure 12.** Disassembly/reassembly of duck HBcAg particle with and without nucleic acids. Lane 1: duck HBcAg; Lane 2: duck HBcAg treated with MgCl<sub>2</sub> and dialysed vs. TBS; Lane 3: duck HBcAg treated with both MgCl<sub>2</sub> and Rnase A and dialysed.; Lane 4: duck HBcAg treated with Rnase A and dialysed.

**Figure 13.** Disassembly/reassembly of duck HBcAg(1-239) particle with and without nucleic acids. Lane 1: duck HBcAg(1-239); Lane 2: duck HBcAg(1-239) treated with  $MgCl_2$  and dialysed vs. TBS; Lane 3: duck HBcAg(1-239) treated with  $MgCl_2$  but not dialysed; Lane 4: duck HBcAg(1-239) treated with Rnase A and dialysed; Lane 5: duck HBcAg(1-239) treated with both  $MgCl_2$  and Rnase A and dialysed.

**Figure 14.** Disassembly/reassembly of duck HBcAg(1-239) particle with and without nucleic acids. Lane 1: duck HBcAg(1-239) treated with both Rnase A and  $MgCl_2$  and dialysed vs. TBS; Lane 2: duck HBcAg(1-239) treated with both Rnase A and  $MgCl_2$  and dialysed vs. TBS; exogenous oligonucleotides were added prior to dialysis; Lane 3: duck HBcAg(1-239).

**Figure 15.** Disassembly/reassembly of duck HBcAg(1-239) particle with and without nucleic acids. Lane 1: duck HBcAg(1-239); Lane 2: duck HBcAg(1-239) treated with both Rnase A and  $MgCl_2$  and dialysed vs. TBS; exogenous oligonucleotides were added prior to dialysis.

**Figures 16A, 16B and 16C.** Disassembly/reassembly of duck HBcAg(1-239) particle with exogenous nucleic acid: confirmation by chromatography. 16A: Peak 1: breakthrough material representing large molecular weight bacterial aggregates; Peak 2: Duck HBcAg native core peak. 16B: Peak 3: disassociated core monomers; Peak 4: exogenous DNA. 16C: Peak 5: Re-associated duck HBcAg core particles; Peak 6 unincorporated exogenous DNA.

**Figure 17.** Amino acid sequence of duck HBcAg (1-239).

**Figure 18.** Nucleic acid sequence of duck HBcAg (1-239).

**Figure 19.** Amino acid sequence of t-duck HBcAg.

Figure 20. Nucleic acid sequence of t-duck HBcAg.

**DETAILED DESCRIPTION OF THE PREFERRED  
EMBODIMENTS OF THE INVENTION**

**Definitions:**

5     Antibody: a molecule that is a member of a family of glycosylated proteins called immunoglobulins (e.g. IgG, IgE, etc.), which can specifically combine with an antigen.

10     Antigen: term used historically to designate an entity that is bound by an antibody, and also to designate the entity that induces the production of the antibody. More current usage limits the meaning of antigen to that entity bound by an antibody, while the word "immunogen" is used for the entity that induces antibody production. Where an entity discussed herein is both immunogenic and antigenic, reference to it as either an immunogen or antigen will typically be made according to its intended utility.

15     Antigenic determinant: the actual structural portion of the antigen that is immunologically bound by an antibody combining site or T cell receptor. The term is interchangeable with "epitope".

20     Cytokine: Protein hormones which promote cell proliferation and differentiation. Cytokines are secreted by immune cells (T-cells, B-cells, macrophages, dendritic cells, etc.) in response to antigenic stimulation.

GM-CSF: Granulocyte-monocyte colony stimulating factor is a cytokine that generally acts on bone marrow to increase the production of inflammatory leukocytes. It also is a macrophage-activating factor and promotes the differentiation of Langerhans cells into dendritic cells.

Hapten: a disease specific antigenic determinant identified by biochemical, genetic or computational means.

5 HBcAg: T cell stimulating proteins or polypeptides having an amino acid residue sequence that corresponds to an amino acid residue sequence encoded by the hepatitis B virus nucleocapsid protein gene.

IFN- $\gamma$ : Interferon- $\gamma$  is produced by activated CD4+ and CD8+ T cells and by NK cells. Production of IFN- $\gamma$  is a direct consequence of antigen activation and is enhanced by the presence of the cytokines IL-2 and IL-12.

10 Monocytic cells: A monocytic cell is released from bone marrow as an incompletely differentiated cell and is referred to as a "monocyte".

Nucleic acid (or oligonucleotide): polymeric form of nucleotides at least five bases in length. The nucleotides may be deoxyribonucleotides, ribonucleotides, or modified forms of either. They may be double- or single-stranded.

15 Polypeptide or peptide: a linear series of amino acids connected to each other by peptide bonds between the alpha-amino and carboxy groups of adjacent amino acids. They can be a variety of lengths, whether in their neutral (uncharged) forms, or forms which are salts, and whether free of or containing modifications such as glycosylation, side chain oxidation,  
20 phosphorylation and the like. Also included are proteins modified by additional substituents such as glycosyl units, lipids, or inorganic ions such as phosphates, as well as modifications relating to chemical conversions or the chains, such as oxidation of sulfhydryl groups.

Protein: a polypeptide having about 70 or more amino acids.

25 TH (as in TH1 and TH2): T helper cells. Naive CD4+ cells can differentiate

into the subsets TH1 and TH2. This differentiation is influenced by the cytokine environment produced early in response to a microbe that triggers an immune response. The principal effector function of TH1 cells is the phagocyte-mediated defense against infection. TH2 cells are primarily  
5 involved in the development of an antibody and allergenic immune response.

The instant invention provides a new type of vehicle for use in the presentation of haptens for the purpose of eliciting an immune response, and for the delivery of nucleic acids for use in enhancing an immune response, for gene therapy, and for other uses. The vehicle is a particle, the structure  
10 of which is based in part on the duck hepatitis B viral core antigen (duck HBcAg). Applicants have discovered that particles formed by assembling recombinant forms of duck HBcAg are highly immunogenic, eliciting a TH1 type immune response and that the particles can be disassembled and reassembled under relatively mild, non-denaturing conditions. This latter  
15 finding, coupled with known recombinant DNA techniques, opens the prospect of generating particles which carry a wide variety of different haptens on a single particle. Further, the reversible disassembly process provides a means to generate particles that contain nucleic acids which may be immune stimulating (in order to further enhance the immune response), or  
20 which may be useful for some other purpose (e.g. for genetic therapy).

Native duck HBcAg particles are 32-34 nm particle composed of 240 identical subunit monomers and are very similar in structure to those of human HBcAg. However, Applicants have found that *duck HBcAg is not cross-reactive with woodchuck or human HBcAg antibodies*. This is an  
25 important finding for two reasons: firstly, the use of duck HBcAg particles as hapten carriers would not interfere with current protocols for detecting human HBcAg since no anti-human HBcAg antibodies would be generated. Secondly, individuals which already have anti-human HBcAg antibodies would still be able to be immunized with the duck HBcAg. This discovery  
30 therefore represents a significant advance in the development of particulate vaccine vehicles.

In preferred embodiments of the present invention, the primary amino acid sequences of the monomers which make up the particles of the present invention, and the nucleic acid sequences which encode them, are "derived from" duck HBcAg. Duck HBcAg monomers consist of 262 amino acids (shown in Figure 1, SEQ ID #1), with an assembly domain comprised of residues 1-200 and an arginine rich nucleic acid binding domain consisting of residues 201-262. By "derived from" we mean that the present invention encompasses particles composed of recombinant monomers whose sequences are identical to those of native duck HBcAg, and also of recombinant monomers with variations in both the amino acid and/or the nucleic acid sequences of duck HBcAg. For example, alternative cloning sites may be genetically engineered into the nucleic acid sequence for the purpose of moving the sequence into a vector, inserting haptens, amino acids substitutions may be made, etc. Any genetic engineering possibility known to those of skill in the art may be applied so long as the resulting monomers still retain the ability to function in the practice of the present invention. In particular, the duck hepatitis B core protein shown in Figure 1 is able to assemble into a particle as shown in Figure 3. The protein and nucleic acid sequences corresponding to duck HBcAg may be modified by deletions, insertions, or substitutions as necessary in order to carry out or to optimize the practice of the present invention, and all such modifications are intended to be within the scope of the present invention. A modified protein derived from duck hepatitis B core protein could include one or more haptens inserted into SEQ ID #1 (or the truncated versions shown in Figures 17 and 19, or other truncated versions) and would have the ability to assemble into a particle as shown in Figure 3. The methods for carrying out such genetic modifications are well known to those of skill in the art.

In a preferred embodiment of the present invention, the monomer sequences are derived from a recombinant form of duck HBcAg known as BC-201D, the amino acid sequence of which is given in Figure 1 (SEQ ID #1). The nucleic acid sequence which encodes BC-201D is given in Figure 2 (SEQ ID #2). The correspondence between the single letter code and the

amino acids or nucleic acid bases are given in Table 1.

**TABLE 1.** Table of Correspondence Between Single Letter Code and Amino Acid or Nucleotide Base

	<b>SYMBOL</b>	<b>AMINO ACID</b>
5	Y	L-tyrosine
	G	glycine
	F	L-phenylalanine
	M	L- methionine
	A	L-alanine
10	S	L-serine
	I	L-isoleucine
	L	L-leucine
	T	L-threonine
	V	L-valine
15	P	L-proline
	K	L-lysine
	H	L-histidine
	Q	L-glutamine
	E	L-glutamic acid
20	Z	L-glutamic acid or L-glutamine
	W	L-tryptophan
	R	L-arginine
	D	L-aspartic acid
	N	L-asparagine
25	B	L-aspartic acid or L-asparagine
	C	L-cysteine
	<b>SYMBOL</b>	<b>NUCLEOTIDE BASE</b>
	A	adenine

C	cytosine
G	guanine
T	thymine

Recombinant duck HBcAg when made in, for example, *Escherichia coli* spontaneously self-assembles into macromolecular core particles. With respect to obtaining particles for use in the practice of the present invention, the means of generating appropriate quantities of particles and purifying them are well known to those of skill in the art. See, for example, U.S. Patents Nos. 4,356,270 to Itskura and 4,563,423 to Murray et al., whose disclosures are incorporated herein by reference.

In a preferred embodiment of the present invention, the particles of the present invention are produced in an *E. coli* recombinant system. However, the particles may be produced by expression of the monomers in a variety of other recombinant expression systems. For example, yeast, insect cells (using for example, a baculovirus expression vector), plant cells (e.g. tobacco, potato, corn, etc.), transgenic animals, or mammalian cell culture systems. Any appropriate expression system that correctly produces the particles of the present invention may be used in the practice of the present invention. Such systems and their use for the production of recombinant proteins are well known to those of skill in the art.

In a preferred embodiment of the present invention, the particles will be comprised of monomers which have been genetically engineered to contain one or more foreign (i.e. non-duck) haptens. The haptens will be carried by the particle into the host upon vaccination and thus presented to the immune system of the host. Examples of such foreign, non-duck haptens include but are not limited to haptens associated with double-stranded DNA or RNA viruses, single-stranded DNA or RNA viruses, intracellular parasites, fungi, bacteria and cancer. Exemplary immunogens of particular importance are derived from bacteria such as *A. pertussis*, *S. paratyphoid* A and B, *C. diphtheriae*, *C. tetanus*, *C. botulinum*, *C. perfringens*, *A.*



*anthracis, A. pestis, V. cholera, N. gonorrhea, H. influenzae, T. palladium* and the like; and immunogens derived from viruses such as polio virus, adenovirus, parainfluenza virus, measles, mumps, respiratory syncytial virus, influenza virus, equine encephalomyelitis, hog cholera virus, Newcastle virus, fowl pox virus, rabies virus, feline and canine distemper virus, foot and mouth disease virus, human and simian immunodeficiency viruses, and the like; rickettsiae immunogen such as epidemic and endemic typhus, and the spotted fever groups, and the like. Any hapten that can be inserted into the monomeric subunits of the particles of the present invention and to which it is desirable to elicit an immune response, may be utilized in the practice of the present invention. The sequence of duck HBcAg is known, and the sequences of many appropriate haptens are known by those of skill in the art, as are the recombinant DNA techniques which are necessary for hapten insertion.

Several methods to confirm that the expressed particles contain the desired hapten are well known to those of skill in the art. For example, the sequence of the monomer may be determined by any of several well-known methods of amino acid sequencing.

In preferred embodiments of the present invention, a single copy of one hapten, several copies of one hapten, or copies of several different haptens may be inserted into a single region or several regions of the recombinant duck HBcAg monomer. The particle of the present invention is thus a highly versatile vehicle for the presentation of haptens, providing extensive flexibility in the design of immunogenic particles.

In preferred embodiments of the present invention, the regions into which the haptens may be inserted are those which, upon particle assembly, will elicit an immune response to the hapten. In a preferred embodiment of the present invention, the amino acids comprising the haptens are inserted in a manner such that they replace an equal number of amino acids of the recombinant monomer. In other embodiments, fewer or more or no recombinant monomer amino acids may be replaced by the hapten. In general, haptens of about 10 to 30 amino acids in length may be efficaciously

inserted into a recombinant monomer. However, haptens of greater or lesser length may also be inserted. An inserted hapten (or haptens if more than one copy is inserted) will ultimately be flanked by amino-terminal and carboxy-terminal flanking sequences which correspond in sequence to duck HBcAg protein, or sequences which have been derived from duck HBcAg protein. In addition, more than one copy of a hapten may be inserted at a single site, or at different sites on the same monomer, or different haptens may be inserted in tandem at a single site, or different haptens may be inserted at different sites on the same monomer. Any length and combination of haptens may be inserted so long as the monomer that is produced is able to assemble into particles which elicit an immune response.

The selection of regions into which haptens may be inserted may be made by comparison to the known primary sequence and three-dimensional structure of related hepatitis core antigen molecules, e.g. human HBcAg. See, for example, Bringas (1997) and Wynne, et al. (1999) for detailed discussions of human hepatitis virus core protein structure. Those of skill in the art will recognize that several methods exist for the comparative alignment of functional domains of related proteins such as human HBcAg and duck HBcAg.

In another preferred embodiment of the present invention, the particles of the present invention are comprised of monomers without a non-duck hapten. These particles may or may not contain nucleic acids. For example, a truncated form of duck HBcAg (t-duck HBcAg) from which the nucleic acid binding domain has been deleted, may be used as a general immune stimulatory agent (e.g. as an adjuvant) in and of itself. Further, particles comprised of monomers without a non-duck hapten may contain nucleic acids (either random nucleic acids from the recombinant host, or defined nucleic acids which are added during reassembly of the particles) and serve as a delivery mechanism for those nucleic acids. Defined nucleic acids may be delivered by the particle for the purposes of gene therapy or gene medicine, such as the delivery of anti-sense RNA, DNA sequences which encode a therapeutic agent, and the like.

In order to determine whether a particle is stimulating an immune response, a "stimulation index" may be measured. The stimulation index is a measure of the ability of a particle to effect an immune response and can be tested in various immune cell assays by measuring immune parameters, e.g. antibody forming capacity, number of lymphocyte subpopulations, mixed leukocyte response, lymphocyte proliferation, and the like. The stimulation of the immune response can also be measured in an assay to determine resistance to infection or tumor growth. Methods of measuring a stimulation index are well known to those of skill in the art. For example, one assay is the incorporation of  $^3\text{H}$  uridine in a murine B cell culture. The culture is contacted with  $10\mu\text{g}$  of particle for 20 hours at  $37^\circ\text{C}$  and then pulsed with  $^3\text{H}$  uridine, 4 hours later cells are harvested and  $^3\text{H}$  uridine incorporated into RNA is measured. The induction of secretion of a particular cytokine can also be used to assess the stimulation index. Without meaning to be bound by theory, for use *in vivo* (e.g. to treat a subject at risk of exposure to a pathogenic agent) it is important that the particle be capable of effectively inducing cytokine secretion by monocytic cells and/or natural killer (NK) cell lytic activity. In one method, the stimulation index of the particle with regard to B-cell proliferation is at least about 5, preferably at least about 10, more preferably about 15, and most preferable at least about 20, while recognizing that there are differences in the stimulation index among individuals.

Due to their high level of versatility, the particles of the present invention may be of several types. Firstly, they may be either "non-mosaic" or "mosaic" in nature. By "non-mosaic" we mean a particle containing a single type of hapten. The monomers which make up non-mosaic particles may carry a single copy of a hapten or two or more copies of the same hapten. The hapten(s) may be inserted in a single region or in more than one region of the monomer.

Mosaic particles are particles which contain two or more different haptens. Mosaic particles may be either "intrinsic" or "extrinsic". Intrinsic mosaic particles are those composed of monomers in which two or more

different haptens are present *on the same monomer*. Intrinsic mosaic particles may be generated by genetically engineering two or more different haptens into a region or regions of a single monomer subunit.

Extrinsic mosaic particles are those containing two or more different haptens in which the different haptens are present *on different monomers*, and the particle is formed from a mixture of such monomers. One means of generating such extrinsic mosaic particles is to produce two or more different non-mosaic particles (or two or more different mosaic and non-mosaic particles), disassemble them into monomers, mix the monomers and allow them to reassemble into particles. Each reassembled particle will be comprised of a mixture of monomers of each type and will thus display a mixture of haptens.

The development of the extrinsic mosaic particles of the present invention was made possible by the discovery by Applicants that recombinant duck HBcAg particles can be reversibly disassembled under mild, non-denaturing conditions. This discovery allows the relatively facile production of a wide variety of extrinsic mosaic particles containing from one to several hundred different haptens per particle for presentation to the immune system. In this way, the particles of the present invention may be used to immunize against a plethora of quasispecies in a single immunization. This is a significant improvement over previous hapten carriers.

The reason that recombinant duck HBcAg particles can be disassembled under mild conditions is that the monomers have only a single cysteine residue and it is present in the free, sulfhydryl form. In contrast, human HBcAg monomers are connected to one another in the particle by numerous disulfide bonds, requiring harsh conditions to disassemble the particle.

The ability to disassemble and reassemble the particles of the instant invention provides a way of carrying out another facet of the present invention. Recombinant duck HBcAg monomers have an intrinsic ability to bind nucleic acid molecules as a result of possessing a nucleic acid binding

domain (arginine rich amino acid residues 201-262). The natural function of the nucleic acid binding domain is to allow Hepatitis B viral particles to bind and "package" their own genetic material and thus transport it from cell to cell and from host to host during an infection. The particles of the present invention, when isolated from, for example, an *E.coli* recombinant expression system, carry within themselves a short, heterogeneous population of random nucleic acids from the bacterial host. The particles of the present invention may be disassembled, the monomers may be separated from the host nucleic acid, and the monomers may then be reassembled in the presence of a different nucleic acid of choice. The nucleic acid of choice will be bound by the monomers and "packaged" into the reassembled particle.

The particles of the present invention may be reassembled to contain any nucleic acid of choice. Examples of such nucleic acids include but are not limited to single- and/or double-stranded DNA and/or RNA, (or DNA/RNA hybrids). The nucleic acids may be delivered for any therapeutic purpose, for example, in order to be transcribed or translated into a therapeutic entity, or to bind to other nucleic acids already present in the body in order to enhance or prevent the transcription or translation of those nucleic acids. For use in the instant invention, the nucleic acids can be synthesized *de novo* using any of a number of procedures well known in the art. For example, the  $\beta$ -cyanoethyl phosphoramidite method (Beaucage and Caruthers, 1981); nucleoside H-phosphonate method (Garegg et al, 1986; Froelder et al., 1986; Garegg et al, 1986; and Gaffney et al., 1988). These chemistries can be performed by a variety of automated oligonucleotide synthesizers available in the market. Alternatively, oligonucleotides can be prepared from existing nucleic acid sequences (e.g. genomic or cDNA) using known techniques, such as those employing restriction enzymes, exonucleases, or endonucleases.

For use *in vivo*, nucleic acids are preferably resistant to degradation (e.g. via endo- and exo-nucleases). Secondary structures, such as stem loops, can stabilize nucleic acids against degradation. Alternatively, nucleic

acid stabilization can be accomplished via phosphate backbone modifications. A preferred stabilized nucleic acid has at least a partial phosphorothioate modified backbone. Phosphorothioates may be synthesized using automated techniques employing either phosphoramidate or H-phosphonate chemistries. Aryl- and alkyl-phosphonates can be made, e.g. as described in U.S. Patent No. 4,469,863; and alkylphosphotriesters (in which the charged oxygen moiety is alkylated as described in U.S. Patent No. 5,023,243 and European Patent No. 092,574) can be prepared by automated solid phase synthesis using commercially available reagents.

10 Methods for making other DNA backbone modifications and substitutions have been described (Uhlmann and Peyman, 1990; Goodchild, 1990).

The nucleic acids can include the use of phosphothioate or phosphodithioate rather than phosphodiesterase linkages within the backbone of the molecule, or methylphosphorothiate terminal linkages (Kreig et al., 1996; Bogg, et al., 1997). The phosphate backbone modification can occur at the 5' end of the nucleic acid, for example at the first two nucleotides of the 5' end of the nucleic acid. The phosphate backbone modification can occur at the 3' end of the nucleic acid, for example at the first two nucleotides of the 3' end of the nucleic acid.

15 Nontraditional bases such as inosine and queosine, as well as acetyl-, thio- and similarly modified forms of adenine, cytidine, guanine, thymine and uridine can also be included, which are not as easily recognized by endogenous endonucleases. Other stabilized nucleic acid molecules include: nonionic DNA analogs, such as alkyl- and aryl phosphonates (in which the charged oxygen moiety is alkylated). Nucleic acid molecules which contain a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini, are also included. The term "oligonucleotide" includes both single and double stranded forms of DNA.

20 In a preferred embodiment of the present invention, the particles of the present invention will be reassembled to contain immune stimulating nucleic acids. Such immune stimulating nucleic acids have been recently described (Carson and Raz, 1997; Davis et al., 1998; Kreig et al., 1995;

Lipford et al, 1997a; Lipford et al, 1997b; Pisetsky, 1996; Sparwasser et al., 1997; Sparwasser et al., 1998; Stacey et al., 1996; Sun et al., 1998; and Zimmerman et al, 1998). DNA was first described as an immune stimulator when it was observed that bacterial DNA caused regression of transplantable tumors *in vivo* without direct tumor cytotoxicity. This tumor resistance induced by DNA resulted from increased natural killer (NK) cell activity. NK activity could be stimulated by DNA from a variety of bacterial sources but not by mammalian DNA, indicating that base modifications and/or nucleotide sequence, rather than the DNA backbone, is the critical mediator of NK stimulation. Studies assessing the immune stimulatory activity of randomly chosen oligonucleotides indicated that a defined motif (RACGTY, where R = A or G and Y = C or T) caused a potent induction of NK cells. With respect to mammalian DNA, this sequence is under-represented and when this sequence is found in mammalian DNA, it is masked by modification. Experiments have determined that oligonucleotides with these modified sequences have no NK or other immune stimulatory activity. The mechanism of immune stimulation by these nucleic acids is as yet unknown. It is known that the production of cytokines IL-12, TNF- $\alpha$ , IL-6, and IL-1 in antigen presenting cells (APC) is stimulated. Initial studies indicate that the individual levels of these cytokines can be modulated by changing the sequence surrounding the defined immune stimulating motif.

The use of immune stimulating nucleic acids in vaccines has been previously described. For example, United States Patent 5,723,335 to Hutcherson et al. and PCT International Application Publication Number WO 98/40100, both of which are incorporated herein by reference, describe the use of immunopotentiating nucleic acids to enhance immune responses to vaccines. However, the delivery mechanism is simply to inject the nucleic acids along with other vaccine components, a method which may not deliver sufficient quantities of nucleic acids in an efficacious manner.

Bacterial DNA appears to enter immune cells by bulk phase endocytosis or protocytosis where it is then processed by antigen presenting cells. Antigen presenting cells appear to process the particles of the present

invention either by bulk phase endocytosis or receptor mediated endocytosis. By including the immune stimulating nucleic acids as an intrinsic part of the particle, they will be carried into the host in concentrated form and processed directly by antigen presenting cells, maximizing their effect as adjuvants.

5 In a preferred embodiment of the present invention, the immune stimulating nucleic acids will be characterized by oligonucleotides with the base sequence 5'-RACGTY-3' (SEQ ID #20) surrounded by up to 20 nucleotides on either side. Preferably the immune stimulatory oligonucleotide is in the range of about 8 to 30 bases in size. For use in the instant invention, the nucleic acids can be comprised of various modified bases as listed above, and synthesized *de novo* using any of a number of procedures well known in the art as listed above. For example, International Patent Application WO 95/26204, entitled "Immune stimulation by phosphorothioate oligonucleotide analogs" reports the nonsequence-specific immunostimulatory effect of phosphorothioate modified oligonucleotides. Alternatively, CpG dinucleotides can be produced on a large scale in plasmids (Sambrook et al., 1989) which after being administered to a subject are degraded into oligonucleotides. Oligonucleotides can be prepared from existing nucleic acid sequences (e.g. genomic or cDNA) using known techniques, such as those employing restriction enzymes, exonucleases, or endonucleases.

20 The immune stimulatory nucleic acids may stimulate cytokine production (e.g. IL-6, IL-12, IFN- $\gamma$ , TNF- $\alpha$  and GM-CSF). Exemplary sequences include but are not limited to:

TCCATGTCGCTCCTGATGCT (SEQ ID #3)

TCCATGTCGTTCCCTGATGCT (SEQ ID #4)

TCGTCGTTTTGTCGTTTTGTCGTT (SEQ ID #5)

30 The immune stimulatory nucleic acids may stimulate natural killer cell (NK) lytic activity in a subject. Specific but nonlimiting examples of such sequences include:



TCGTCGTTGTCGTTGTCGTT (SEQ ID #6)  
TCGTCGTTTTGTCGTTTTGTCGTT (SEQ ID #7)  
TCGTCGTTGTCGTTTTGTCGTT (SEQ ID #8)  
GCGTGCGTTGTCGTTGTCGTT (SEQ ID #9)  
5 TGTGTTTTGTCGTTTGTGCGTT (SEQ ID #10)  
TGTGTTGTCGTTGTCGTT (SEQ ID #11)  
TCGTCGTCGTCGTT (SEQ ID #12).

The immune stimulatory nucleic acids may stimulate B cell proliferation. Specific, but nonlimiting examples of such sequences include:

10 TCCTGTCGTTCCCTTGTGCGTT (SEQ ID #13)  
TCCTGTCGTTTTTTGTGCGTT (SEQ ID #14)  
TCGTCGCTGTCTGCCCTTCTT (SEQ ID #15)  
TCGTCGCTGTTGTCGTTTCTT (SEQ ID #16)  
TCGTCGTTTTGTGTTTTGTGCGTT (SEQ ID #17)  
15 TCGTCGTTGTCGTTTTGTGCGTT (SEQ ID #18)  
TGTCGTTGTCGTTGTCGTT (SEQ ID #19).

Any appropriate immune stimulating nucleic acid may be utilized in the practice of the present invention.

The present invention provides a method for the disassembly and  
20 reassembly of the particles of the present invention under relatively mild, physiological conditions. In general, the method entails 1) providing particles comprised of a plurality of nucleocapsid protein monomers, the primary amino acid sequences of which are derived from duck hepatitis B virus, wherein said plurality of monomers are assembled to form a particle;  
25 2) exposing the particles to a charged agent; and 3) removing the charged agent. Upon removal of the charged agent, the monomers spontaneously reassemble into particles. A preferred embodiment of the method is as follows: Particles may be isolated from a recombinant expression system by a simple four-step method. For example, cells are pelleted by centrifugation and lysed by a French press. Ammonium sulfate is added to 277g/L.  
30 Precipitated material is collected by centrifugation and resuspended in

phosphate buffer and dialyzed against phosphate buffer overnight. The resulting dialysate is applied to a hydroxyapatite column and washed with phosphate buffer until the optical density at 280nm is below 0.1. 277 g/L of ammonium sulfate is added to the pooled fractions and the precipitate  
5 collected by centrifugation. The resulting pellet is resuspended in minimal buffer and applied to a Sepharose-CL4B size exclusion chromatography column. Peak fractions representing the particles are determined by SDS-PAGE and pooled. The particles are resuspended in neutral buffer (e.g. 20mM Tris HCl, pH 7.0) and high (0.1 to 1 M) divalent cation  
10 concentrations, such as  $Mg^{+2}$ ,  $Zn^{+2}$ ,  $Ba^{+2}$ ,  $Ca^{+2}$ ,  $Pb^{+2}$  and  $Sr^{+2}$ . The particles are allowed to dissociate into monomers (with gentle mixing) for approximately 1 hour and the progress of dissociation may be monitored by Fast Protein Liquid Chromatography (FPLC) Sepharose-CL4B size-exclusion column chromatography, or native agarose gel electrophoresis.  
15 Ribonuclease A may be added to remove nucleic acids (e.g. recombinant host nucleic acids) which were contained within the particles as originally isolated. Reassembly is effected in the following manner: For the truncated form of duck HBcAg (t-duck HBcAg), from which the nucleic acid binding domain has been deleted, reassembly and particle formation occurs upon  
20 simple dialysis against an appropriate buffer plus 100-200mM NaCl. The non-truncated form of duck HBcAg reassembles only in the presence of nucleic acids. Thus, the monomers may be mixed with the nucleic acid of choice, dialyzed against an appropriate buffer, upon which dialysis reassembled particles containing the nucleic acid are formed. In a preferred  
25 embodiment of the present invention, the molar ratio of nucleic acid to monomer is about 1:1. Exogenous DNA which was not incorporated into the reassembled particles may be removed by size-exclusion column chromatography. Those of skill in the art will recognize that many minor variations in the practice of the method of the present invention may be  
30 undertaken without significantly altering the outcome of the method. For example, the procedure may be "scaled up" or "scaled down" for production purposes. In addition, some variations may be beneficial for optimizing the

procedure for a particular monomer type, e.g. variations in ionic strength, pH, exact ratio of nucleic acid to monomer, and the like. All such variations and optimizations are included in the scope of the method of the present invention.

5           The disassembly/reassembly process is illustrated in Figure 3. In this figure, a particle 10 is comprised of duck HBcAg monomers 11 containing a hapten specific for, for example, pertussis, and a particle 20, is comprised of duck HBcAg monomers 21 containing a hapten specific for, for example, polio. Particles 10 and 20 are exposed to a charged agent (e.g. a divalent  
10           cation) upon which exposure particles 10 and 20 disassemble into monomers 11 and 21. Unwanted nucleic acids which were contained within the particles may be removed, for example, by the addition of a nuclease. After removal of the nuclease, specific nucleic acids 30 may be added to the mixture of monomers 11 and 21. Upon removal of the charged agent, the  
15           monomers 11 and 21 reassemble to form an extrinsic mosaic particle 40, which contains nucleic acids 30.

          In another aspect of the present invention, the foreign, non-duck hapten(s) may be attached to the particle rather than genetically engineered into the monomer sequence. The individual polypeptide haptens (for  
20           example a polypeptide, carbohydrate, and the like) can be operatively linked to the particle through an amino acid residue side chain to form an immunogenic conjugate, i.e. a branched-chain polypeptide and/or polypeptide/carbohydrate polymer. Such particles are to be considered  
25           "derived from" duck HBcAg as described above and are contemplated for use within the practice of this invention.

          The present invention provides particles for use in eliciting an immune response in a host. In a preferred embodiment of the present invention, the particles may be used as a vaccine in the classical sense, i.e. prophylactically in order to prime the host immune system prior to exposure  
30           to a disease causing entity. In yet another preferred embodiment of the present invention, the particles of the present invention may be used therapeutically, i.e. to boost the immune response of a subject against a

pathogen which has already infected the subject, for example in the case of HIV infection.

The present invention also provides a composition for use in eliciting an immune response comprising the particles of the present invention. The preparation of such compositions for use as vaccines is well known to those of skill in the art. Typically, such compositions are prepared either as liquid solutions or suspensions, however solid forms such as tablets, pills, powders and the like are also contemplated. Solid forms suitable for solution in, or suspension in, liquids prior to administration may also be prepared. The preparation may also be emulsified. The active ingredients may be mixed with excipients which are pharmaceutically acceptable and compatible with the active ingredients. Suitable excipients are, for example, water, saline, dextrose, glycerol, ethanol and the like, or combinations thereof. In addition, the composition may contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents, and the like. In addition, the composition may contain other adjuvants. If it is desired to administer an oral form of the composition, various thickeners, flavorings, diluents, emulsifiers, dispersing aids or binders and the like may be added. The composition of the present invention may contain any such additional ingredients so as to provide the composition in a form suitable for administration. The final amount of active ingredient in the formulations may vary. However, in general, the amount of active ingredient (particles) in the formulations will be from 1-99%.

The present invention also provides a method for eliciting an immune response in a subject, comprising administering to said subject an effective amount of a composition comprising the particles of the present invention. By effective amount we mean an amount of the composition of the present invention necessary to prevent, cure or at least partially arrest the symptoms of the subject. The subject may be any vertebrate, for example, any mammalian (e.g. human) or avian species. The exact amount of the compound to be administered will vary from subject to subject and may depend on, for example, weight, gender, age, overall physical condition, and

the like. Such variables well understood by those of skill in the art and are best assessed by skilled practitioners in the art.

The compositions of the present invention may be administered in any of a variety of ways which are well known to those of skill in the art and include but are not limited to: parenterally (e.g. subcutaneously or by  
5 intradermal or intramuscular injection), orally, ophthalmically, vaginally, rectally, intranasally, transdermally, and the like. Any appropriate method of administration may be utilized in the practice of the present invention so long as the compositions are delivered in an effective manner.

10 The following examples illustrate are given in order to illustrate several aspects of the invention, and should not be interpreted in any way to restrict the applications of the invention.

## EXAMPLES

### Materials

15 *Duck HBcAg particles*: Duck HBcAg particles were obtained from an *E. coli* recombinant expression system. The duck HBcAg particles have the amino acid sequence depicted in Figure 1 (SEQ ID #1) and may contain a heterogeneous population of host-derived nucleic acids. The duck HBcAg (1-239) particles have the amino acid sequence depicted in Figure 17 (SEQ  
20 ID #21) and the nucleic acid sequence depicted in Figure 18 (SEQ ID #22). The t-duck HBcAg particles have the amino acid sequence depicted in Figure 19 (SEQ ID #23) and the nucleic acid sequence depicted in Figure 20 (SEQ ID #24). t-duck HBcAg ("truncated" duck HBcAg) particles are composed of monomeric subunits in which the nucleic acid binding domain  
25 has been deleted by genetic engineering.

### Methods

*Quantization of specific RNAs*. Specific RNAs produced by J774A.1 macrophage cells were quantified after exposure to different types of stimuli:  
1) duck HBcAg particles which contained nucleic acids or 2) t-duck HBcAg  
30 particles which do not contain nucleic acids. Cells were treated with 10µg

of either duck HBcAg or t-duck HBcAg and total RNA was isolated from duplicate samples at various time points. Total RNA was reverse transcribed using random hexamers, and PCR was then performed in the linear range using gene specific primers. PCR products were analyzed by gel  
5 electrophoresis and quantified by densitometry. Prior to use, recombinant proteins were treated with Triton X-114 three times to remove lipopolysaccharide contaminants.

*Quantization of IL-12:* Capture ELISA was used to determine IL-12 p70 protein in cell culture media and cell extracts with R&D ELISA kit. IL-12's  
10 biologically active form is a heterodimeric disulfide linked glycoprotein consisting of p35 and p40 subunits. IL-12 is produced by activated antigen presenting cells including macrophages, dendritic cells, and B cells. Following activation p40 expression is induced and translated. The resulting p40 protein binds to the constitutively expressed p30 subunit and is secreted  
15 to perform various biological functions. A capture ELISA was used to determine the concentration of IL-12 secreted by dendritic cells and secreted and located intracellularly in J774A.1 macrophages following treatment with increasing amounts of duck HBcAg. Microplates (12 strips of 8 wells/plate) coated with an antibody to capture IL-12 p70 were incubated with cleared  
20 cell culture media or cell extracts following an 18 hour exposure to duck HBcAg. This mixture was allowed to incubate for 2 hours. Following incubation wells were washed 5 times with wash buffer. Following washing, buffer containing an anti-p70 antibody conjugated to horse radish peroxidase which binds to a separate binding motif than the capture antibody, is added  
25 and incubated for 2 hours at room temp. After incubation the wells are washed once again 5 times. A colorimetric substrate that reacts with the horse radish peroxidase is added for 30 minutes at room temperature, in the dark. After 30 minutes an acidic solution is added to terminate the reaction. The absorbance of each sample is then measured at 450nm and corrected at  
30 540nm. Results are compared to standard reactions performed at the same time under the same conditions and are given in the units pg/ml.

*Flow cytometry:* Cell markers CD4+, CD8+, Ly-6A/E and B7-2 were monitored by flow cytometry in the following manner:

Cell Culture: J774A.1 cells were split to 500,000 cells per well one day prior to the experiment. On the day of the experiment LPS-free duck HBcAg was added directly to the cell culture media to the appropriate concentration and allowed to incubate with the cells for 18 hours. At 18 hours cells were dislodged by pipetting, centrifuged at 500xg for 10 minutes and then washed 3 times in phosphate buffered saline. Cells are then incubated with 10 µg/ml Mouse IgG in phosphate buffered saline (PBS) with 1% bovine serum albumin (BSA) to block Fc receptors. Fluoroccein isothiocyanate (FITC) conjugated primary antibodies against mouse B7.2 (CD86), H-2k<sup>b</sup> (MHC-I), I-A<sup>b</sup> (MHC-II); Ly6A/E and Ly6/C were added respectively and incubated 30 minutes at 4°C. Fluorescein isotype matched non-specific antibodies were used as the negative control. At least 10<sup>5</sup> cells were collected for data analysis. Cells were pelleted by centrifugation and non-bound antibody was washed away with three washes with PBS with 1% BSA. Cells were then resuspended in FACS buffer and cell surface markers quantified by Beck-Dickson FACScanner. Similar methods were used for spleenocytes except the antibodies against mouse CD8-RPE and CD4-RPE (R-phycoerythrin) were also included.

*Quantization of IgG titer, both total and isotypic :* Mice were immunized with lipopolysaccharide free duck HBcAg (0, 1 or 10µg) without adjuvant. At 10 days, 24 days, and then 14 days following secondary immunization, blood was drawn and tested for duck HBcAg antibodies. Approximately 100ul of blood was drawn by retro-orbital puncture. Following the bleed samples were allowed to clot. Clots were removed by centrifugation and the resulting serum contained the IgG fraction. Serum samples were serially diluted from 10(1) to 10(6).

ELISA plates coated with duck HBcAg protein (in the particulate form) were prepared by incubating commercially available ELISA plates

with duck HBcAg protein in bicarbonate buffer overnight at room temperature. Plates were washed 5 times with washing buffer then blocked for non-specific binding with bovine serum albumin (BSA) for two hours at room temperature. Plates were washed 5 times with washing buffer and  
5 stored at 4°C prior to use.

100ul of diluted serum samples were incubated with pre-coated plates for 2 hours at room temperature. Following incubation, wells were washed 5 times with wash buffer. Following washing, buffer containing a rat anti-mouse IgG antibody conjugated with horse radish peroxidase is  
10 added and incubated for 2 hours at room temp. After incubation the wells are washed once again 5 times. A colorimetric substrate that reacts with the horse radish peroxidase is added for 30 minutes at room temperature, in the dark. After 30 minutes an acid stop solution is added and the reaction is  
15 terminated. The absorbance at 450nm of each sample is then measure at 450nm and corrected at 540nm. Results are compared to standard reaction performed at the same time under the same conditions and are given in the units of relative titers.

For isotype specific assay, rat anti-mouse antibody specific for the antibody isotype was used instead of the general rat anti-mouse antibody.  
20 All other conditions remained the same.

*Method for disassembling and reassembling duck HBcAg, duck HBcAg(1-239) and t-duck HBcAg*

It has been discovered that duck HBcAg, duck HBcAg(1-239) and t-duck HBcAg particles can be reversibly assembled between the monomeric  
25 and particulate forms. This process may be carried out under non-denaturing conditions in neutral buffer (e.g. Tris HCl pH 7.0) and high concentrations (e.g. 0.1-1 M) of divalent cations such as  $Mg^{+2}$ ,  $Zn^{+2}$ ,  $Ba^{+2}$ ,  $Ca^{+2}$ ,  $Pb^{+2}$  and  $Sr^{+2}$ . The particles as isolated from the recombinant expression system are  
30 allowed to dissociate into monomers (with gentle mixing) for approximately 1 hour and the progress of dissociation is monitored by FPLC (Pharmacia) Sepharose-CL4B size-exclusion column chromatography, or by native



agarose gel electrophoresis. Ribonuclease A (e.g. 7.5 µg/mL) is added to remove recombinant host nucleic acids which were contained in the particles as isolated Reassembly is effected in the following manner: The non-nucleic acid binding t-duck HBcAg monomers can reassemble by simple dialysis in neutral buffer containing 100-200mM NaCl. The duck HBcAg and duck HBcAg(1-239) monomers are dependent upon the presence of nucleic acids for appropriate reassembly. The monomers are mixed with the nucleic acid of choice and dialyzed against neutral buffer, upon which dialysis reassembled particles containing the nucleic acid are formed. The preferred molar ratio of monomer to oligonucleotide is 1:1. Exogenous DNA which is not incorporated into the reassembled particles may be removed by size-exclusion column chromatography.

#### **EXAMPLE 1. Induction of cytokines *in vitro***

Experiments were conducted as described in Methods in order to determine which, if any, cytokines were induced by the exposure of J774A.1 macrophage cells to recombinant duck HBcAg and t-duck HBcAg. The results are given in Figure 4. As can be seen, increased transcription of the TH1- type cytokines IL-1 $\alpha$ , IL-6 and IL-12 was induced by both duck HBcAg and t-duck HBcAg, indicating that the core protein is responsible for the induction of a TH1 cytokine profile.

#### **EXAMPLE 2. Induction of IL-12 p70 protein production.**

Experiments were conducted *in vitro* to determine whether the addition of duck HBcAg and t-duck HBcAg to J774A.1 macrophage cells and the addition of duck HBcAg to mouse bone marrow-generated dendritic cells induced production of IL-12 p70 protein. Analysis of the quantity of IL-12 p70 in the cell culture media and cell extracts was carried out as described in Methods and the results are given in Figures 5A, 5B and 6. As can be seen, exposure to duck HBcAg and t-duck HBcAg for 72 hours increased the concentration of IL-12 in the culture medium (Figure 5A) and in the cells themselves (Figure 5B) of J774A.1 macrophage cells. Exposure

of mouse bone marrow-generated dendritic cells from both BALB/C and B10 mice to duck HBcAg for 24 hours resulted in an increase in IL-12 in the culture medium (Figure 6). This response is consistent with the induction of a TH1-type immune response.

5      **EXAMPLE 3. Analysis of cell markers on J774A.1 macrophage cells.**

Experiments were conducted *in vitro* to determine whether the addition of duck HBcAg and t-duck HBcAg to J774A.1 macrophage cells could induce the presence of cell markers MHC-I, MHC-II, Ly-6A/E and B7-2. These cell surface markers are directly implicated in a TH1 type  
10 immune response. The presence of cell markers was determined by flow cytometry as described in Methods. The results are given in Figure 6. As can be seen, the data showed that each type of cell surface antigen was upregulated after treatment with duck HBcAg for 18 hours, indicating that macrophages can be stimulated by duck HBcAg and t-duck HBcAg.

15      **EXAMPLE 4. Immunogenicity of duck HBcAg.**

The immunogenicity of duck HBcAg was tested by determining the total IgG titer for duck HBcAg in the following manner: two strains of mice, B10 and BALB/C, were immunized as described in Methods. The results are given in Figure 7. As can be seen, both B10 (Figure 7A) and BALB/C  
20 (Figure 7B) mice generated antibody titers greater than  $10^5$ , indicating that duck HBcAg is highly immunogenic. Further, the isotype of the IgG fraction, depicted in Figure 8, shows a TH1 bias via the production of IgG2a, IgG2b and IgG3. Of particular importance is the fact that BALB/C mice showed a TH1 bias even though their genetic background is normally  
25 biased for a TH2 immune response.

**EXAMPLE 5. Analysis of cell markers on spleenocytes.**

Following the terminal bleed, spleenocytes were obtained from the B10 mice and cultured with 1 $\mu$ g of duck HBcAg for 24 hours. Flow cytometry (as described in Methods) was used to monitor cell markers CD4+, CD8+, Ly-6A/E and B7-2. The results are presented in Figure 9. As can be seen, both the 1 $\mu$ g and 10 $\mu$ g immunized mice had substantial increases in the presence of these cell markers over control cells from non-immunized mice, indicating a strong T-cell response.

**EXAMPLE 6. Demonstration of lack of crossreactivity of duck HBcAg with human and woodchuck HBcAg.**

Experiments were conducted as described in Methods in order to compare the crossreactivity of duck, woodchuck and human HBcAg. As can be seen in Figure 11A, woodchuck antibody displays extensive crossreactivity with human HBcAg and no crossreactivity with duck HBcAg. Likewise, human HBcAg antibody displays extensive crossreactivity with woodchuck HBcAg and no crossreactivity with duck HbcAg (Figure 11A).

**Example 7. Disassembly and reassembly of duck HBcAg particles.**

Experiments were conducted in order to show that the duck HBcAg particles could be successfully disassembled and reassembled. Duck HBcAg (1 mg/mL) was incubated at 37 °C with 0.3 M MgCl<sub>2</sub>, 7.4 ug/mL Rnase A, or both. After 30 minutes each sample was dialyzed against Tris buffered saline (TBS) for 4 hours and analyzed by native agarose electrophoresis. Treatment with magnesium and subsequent dialysis resulted in reassembly of the treated protein into particles that co-migrated (Figure 12, lane 2) with the duck HBcAg standard (Figure 12, lane 1). Treatment with Rnase A alone did not alter the electrophoretic mobility of duck HBcAg (Figure 12, lane 4), suggesting that Rnase A alone has no apparent effect on the duck HBcAg particle. However, treatment with both Rnase A and MgCl<sub>2</sub> results in quantitative removal of a band co-migrating with the duck HBcAg

standard (Figure 12, lane 3). This suggests that in presence of the divalent cation Rnase A can catalyse the hydrolysis of the ribonucleic acid in the particle, i.e. the particle is disassembled, and that nucleic acid is required for the reassembly of the disassociated duck HBcAg. Similar experiments were conducted in which Rnase A/  $MgCl_2$  treated duck HBcAg were supplemented with exogenous DNA and tRNA during the dialysis step. No reassembled particles were detected by these methods.

**Example 8. Disassembly and reassembly of duck HBcAg(1-239)**

**particles.** Duck HBcAg (1-239) was analyzed by the same method described in Example 7. Identical results were obtained and are given in Figure 13. Treatment with magnesium and subsequent dialysis resulted in reassembly of the treated protein into particles that co-migrated (Figure 13, lane 2) with the duck HBcAg(1-239) standard (Figure 13, lane 1). Treatment with Rnase A alone did not alter the electrophoretic mobility of duck HBcAg(1-239) (Figure 13, lane 4), suggesting that Rnase A alone has no apparent effect on the duck HBcAg(1-239) particle. However, treatment with both Rnase A and  $MgCl_2$  results in quantitative removal of a band co-migrating with the duck HBcAg(1-239) standard (Figure 13, lane 3). This suggests that in the presence of the divalent cation Rnase A can catalyse the hydrolysis of the ribonucleic acid in the particle, i.e. the particle is disassembled, and that nucleic acid is required for reassembly.

However, in contrast to results obtained with full length duck HBcAg, the addition of exogenous DNA to Rnase A/  $MgCl_2$  treated duck HBcAg(1-239) supports re-assembly of dissociated monomers into nucleic acid containing core structures. This is illustrated in Figures 14 and 15. Figure 14, Lane 1 shows duck HBcAg(1-239) which has been treated with both Rnase A and  $MgCl_2$  and dialysed vs. TBS. Figure 14, Lane 2 shows duck HBcAg(1-239) which has been treated with both Rnase A and  $MgCl_2$  and dialysed vs. TBS and to which exogenous oligonucleotides were added prior to dialysis. As can be seen, a band migrating at the position of control duck HbcAg(1-239) (lane 3) can be seen, indicating particle reassembly in

the presence of exogenous oligonucleotides. These results are further illustrated in Figure 15. Lane 1 of Figure 15 shows control duck HbcAg(1-239). Lane 2 of Figure 15 shows duck HbcAg(1-239) which has been treated with both Rnase A and MgCl<sub>2</sub> and dialysed vs. TBS, and to which  
5 exogenous oligonucleotides were added prior to dialysis. As can be seen, a band migrating at the position of control duck HbcAg(1-239) (lane 1) can be seen, indicating particle reassembly in the presence of exogenous oligonucleotides.

**Example 9.** Rc-assembly of duck HBcAg(1-239) with exogenous nucleic  
10 acid was confirmed by chromatography on Sepharose 4B. The results are shown in Figure 16, where peak 2 of 16A represents duck HBcAg(1-239) native core peak. (Peak 1 is breakthrough material representing large molecular weight bacterial aggregates). Peak 3 of 16B corresponds to  
disassociated core monomers (after exposure to divalent cations) and Peak 4  
15 is exogenous DNA. Peak 5 of 16C corresponds to duck HBcAg (1-239) core particles which have reassociated after removal of divalent cations and addition of exogenous DNA; peak 6 represents unincorporated exogenous DNA.

## REFERENCES

- 20 Beaucage, S.L. and Caruthers, M.R. *Tet. Let.* 21:1859. 1981.
- Bringas, R. *J. Structural Biol.* 118:189-196. 1997.
- Boggs, R.T. et al., *Antisense and Nucl. Acid Drug Dev.* 1:461-71. 1997.
- Carson, D. and Raz, E. Oligonucleotide adjuvants to T helper 1 (Th1) -  
specific vaccinations. *Journal of Experimental Medicine* 186(10), 1621-  
25 1622. 1997.
- Cookson and Moffatt, *Science* 275:4142. 1997.

- Davis, H., Weeranta, R., Waldschmidt, T., Tygrett, L., Schorr, J., and Krieg, A. M. CpG DNA is a potent enhancer of specific immunity in mice immunized with recombinant hepatitis B surface antigen. *The Journal of Immunology* 160, 870-876. 1998.
- 5 Gaffney, et al., *Tet. Let.* 29: 2619-2622. 1988.
- Garegg et al., *Tet. Let.* 27: 4051-4054. 1986.
- Goodchild, J. *Bioconjugate Chem.* 1:165. 1990.
- Griffiths, J., Harris, S., Layton, G., Berrie, L., French, T., Burns, N., and Kingsman, A., *Journal of Virology*, 1993, (67) 3191
- 10 Harris, S., Gearing, G., Layton, S., and Kingsman, A., *Immunology*, 1992, (77) 315
- Krieg, A. M., Yi, A., Matoson, S., Waldschmidt, T., Bishop, G., Teasdale, R., Koretzky, G., and Klinman, D. CpG motifs in bacterial DNA trigger direct B-cell activation. *Nature* 374, 546-549. 1995.
- 15 Krieg, A.M. et al., *Antisense and Nucl. Acid Drug Dev.* 10: 133-9. 1996.
- Lipford, G. B., Bauer, M., Blank, C., Reiter, R., Wagner, H., and Heeg, K. CpG-containing sythetic oligonucleotides promote B and cytotoxic responses to protein antigen: a new class of vaccine adjuvants. *European Journal of Immunology* 27, 2340-2344. 1997.
- 20 Lipford, G. B., Sparwasser, T., Bauer, M., Zimmermann, S., Koch, E., Heeg, K., and Wagner, H. Immunostimulating DNA: sequence-dependent production of potentially harmful or useful cytokines. *European Journal of Immunology* 27, 3420-3426. 1997.
- Milich, DR., *Seminars in Immunology*, 1990, (2) 307-315
- 25 Milich, DR, Peterson, DL, Zheng, J, Hughes, J, Wirtz, R, and Schodel, F., *Annals of the New York Academy of Science*, 1995, (754) 187-201
- Pisetsky, D. S. Immune activation by bacterial DNA: a new genetic code. *Immunity* 5, 303-310. 1996.
- 30 Raychaudhuri, S. and Rock, K., *Nature Biotechnology*, 1998, (16) 1025-1031
- Schirmbeck, R. et al. *J. Immunology* 152:1110-1119.1994.

- Schirmbeck, R., Bohm, W., Melber, K., and Reimann, J., *The Journal of Immunology*, 1995, (155) 4676-4684
- Schodel, F, Peterson, DL, Hughes, J, and Milich, D., *International Review of Immunology*, 1994, (ii) 153-165
- 5 Schodel, F, Peterson, DL, Hughes, J, and Milich, DR., *Journal of Immunology*, 1992, (66) 106-114
- Schodel, F, Peterson, DL, Zheng, J, Jones, JE, Hughes, JC, and Milich, DR., *Vaccine*, 1993, (11) 143-148
- 10 Sparwasser, T., Koch, E., Vabulas, R., Heeg, K., Lipford, G. B., Ellwart, J., and Wagner, H. Bacterial DNA and immunostimulatory CpG oligonucleotides trigger maturation and activation of murine dendritic cells. *European Journal of Immunology* 28, 2045-2054. 1998.
- 15 Sparwasser, T., Miethke, T., Lipford, G. B., Erdmann, A., Hacker, H., Heeg, K., and Wagner, H. Macrophages sense pathogens via DNA motifs: induction of tumor necrosis factor- $\alpha$ -mediated shock. *European Journal of Immunology* 27, 1671-1679. 1997.
- 20 Stacey, K., Sweet, M., and Hume, D. Macrophages ingest and are activated by bacterial DNA. *The Journal of Immunology* 157, 2116-2122. 1996.
- Sun, S., Kishimoto, H., and Sprent, J. DNA as an Adjuvant: Capacity of insect DNA and synthetic oligonucleotides to augment T cell response to specific antigen. *Journal of Experimental Medicine* 187(7), 1145-1150. 1998.
- Uhlmann, E. and Peyman, A. *Chem. Rev.* 90:544. 1990.
- 25 Wynne, S.A., Crowther, R.A. and Leslie, G.W. *Molecular Cell* 3:771-780. 1999.
- Zimmermann, S., Egeter, O., Hausmann, S., Lipford, G. B., Rocken, M., Wagner, H., and Heeg, K. Cutting edge: CpG oligonucleotides trigger protective and curative Th1 response in lethal murine leishmaniasis. *The Journal of Immunology* 160, 3627-3730. 1998.

**CLAIMS**

We claim:

- 1        1. A composition comprised of a plurality of nucleocapsid protein  
2        monomers, the primary sequences of which are derived from duck hepatitis  
3        B virus, wherein said plurality of monomers are assembled to form a  
4        particle.
- 1        2. The composition of claim 1 wherein at least a first portion of said  
2        nucleocapsid protein monomers include a first hapten.
- 1        3. The composition of claim 2 wherein at least a second portion of said  
2        nucleocapsid protein monomers includes a second hapten different from said  
3        first hapten.
- 1        4. The composition of claim 1 wherein said particle includes a nucleic acid.
- 1        5. The composition of claim 2 wherein said particle includes a nucleic acid.
- 1        6. The composition of claim 3 wherein said particle includes a nucleic acid.
- 1        7. The composition of claim 4 wherein said nucleic acid is selected from the  
2        group consisting of: SEQ IDs 3-19.
- 1        8. The composition of claim 5 wherein said nucleic acid is selected from the  
2        group consisting of: SEQ IDs 3-19.
- 1        9. The composition of claim 6 wherein said nucleic acid is selected from the  
2        group consisting of: SEQ IDs 3-19.
- 1        10. The composition of claim 2 wherein said first hapten is associated with a



2 disease condition caused by an agent selected from the group consisting of:  
3 single stranded DNA viruses, double stranded DNA viruses, single stranded  
4 RNA viruses, double stranded RNA viruses, intracellular parasites, fungi,  
5 bacteria, and cancer.

1 11. The composition of claim 3 wherein said second hapten is associated  
2 with a disease condition caused by an agent selected from the group  
3 consisting of: single stranded DNA viruses, double stranded DNA viruses,  
4 single stranded RNA viruses, double stranded RNA viruses, intracellular  
5 parasites, fungi, bacteria, and cancer.

1 12. The composition of claim 1 further comprising first and second haptens  
2 and said particle is assembled as an extrinsic mosaic.

1 13. The composition of claim 1 further comprising first and second haptens  
2 intrinsic to said nucleocapsid protein monomers and said particle is  
3 assembled as an intrinsic mosaic.

1 14. A method of delivering nucleic acids to a subject in need thereof,  
2 comprising, administering to said subject a composition comprised of a  
3 nucleic acid and a plurality of nucleocapsid protein monomers, the primary  
4 sequences of which are derived from duck hepatitis B virus, wherein said  
5 plurality of monomers are assembled to form a particle, and wherein said  
6 nucleic acid is contained within said particle.

1 15. The method of claim 14 wherein at least a first portion of said  
2 nucleocapsid protein monomers include a first hapten.

1 16. The method of claim 14 wherein at least a second portion of said  
2 nucleocapsid protein monomers includes a second hapten different from said  
3 first hapten.

- 1        17. A nucleocapsid protein monomer particle processing method,  
2        comprising the steps of:  
3                providing a composition comprised of a plurality of nucleocapsid  
4        protein monomers, the primary sequences of which are derived from duck  
5        hepatitis B virus, wherein said plurality of monomers are assembled to form  
6        a particle,  
7                exposing said particle to a charged agent to produce a mixture of  
8        said monomers in a non-particle form, and  
9                removing said charged agent from said mixture to assemble a particle  
10       from nucleocapsid protein monomers in said mixture.
- 1        18. The method of claim 17, further comprising the step of removing  
2        unwanted nucleic acid from said mixture produced during said exposing  
3        step.
- 1        19. The method of claim 17, further comprising the step of adding a nucleic  
2        acid to said mixture produced during said exposing step.
- 1        20. The method of claim 17, wherein said charged agent used in said  
2        exposing step is a divalent cation selected from the group consisting of:  
3         $Mg^{+2}$ ,  $Zn^{+2}$ ,  $Ba^{+2}$ ,  $Sr^{+2}$ ,  $Ca^{+2}$  and  $Pb^{+2}$ .
- 1        21. A method for illiciting an immunogenic response in a patient in need  
2        thereof, comprising the step of administering to said patient an effective  
3        amount of a composition comprised of a plurality of nucleocapsid  
4        monomers, the primary sequences of which are derived from duck hepatitis  
5        B virus, wherein said plurality of monomers are assembled to form a  
6        particle.
-

- 1      22. The method of claim 21 wherein said composition further comprises a
- 2      nucleic acid incorporated within said particle.
  
- 1      23. The method of claim 21 wherein said composition further comprises one
- 2      or more haptens associated with at least a portion of said plurality of
- 3      nucleocapsid monomers.

1 MDINASRALANVYDLPDD<sup>25</sup>FFPKIDDLVRDAKDALEPYWR  
50 SDSIKKHVLIA<sup>75</sup>THFVDLIEDFWQTTQGMHEIAEALRAVI  
100 PPTTPVPAGYLIQHEEAE<sup>125</sup>EIPLGDLFKHQEERIVSFQP  
150 DYPITARIHAHLKAYAKINEESLDRARRLLWWHYNCLLW  
175 GEANVTNYISRLRTWLSTPERYGRDAPTIEA<sup>200</sup>ITRPIQV  
225 AQGGRKTS<sup>250</sup>SGTRKPRGLEP<sup>262</sup>RRRKVKTTVVYGRRRSKSRD  
RRAPSPQ<sup>250</sup>RAGSPLPRSSSSHRRSPSPRK

1/20

FIG.1

2/20

1 50  
ATGGATATCAATGCTTCTAGAGCCTTAGCCAATGTTTATGATTGGCCAGATGATTCTTCCC  
100  
AAAAATTGATGATCTTGTAAAGGATCGGAAGGATGCTTTAGAACCTTATTGGAGATCAGATT  
150  
CAATAAAGAAACATGTTTAAATTGCAACTCACTTTGTGGATCTTATTGAAGACTTCTGGCAA  
200  
ACTACTCAGGGTATGCATGAATAGCTGAAGCCTTAAGAGCAGTTATACCACCTACTACAAC  
250 300  
ACCAAGTCCCGCAGGATATCTGATTACGACGAGAGGCTGAGGAGATTCCCTCTGGGAGATT  
350  
TATTTAAACATCAGGAAGAAAGGATAGTTAGTTTCCAAACCGGATTATCCTATTACTGCACGA  
400  
ATTATGCACACCTGAAAGCTTATGCAAGATTAAACGAGGAATCACTGGATAGGGCTAGGAG  
450  
ATTGCTTTGGTGGCATTACAATTGTTTACTGTGGGAGAAAGCTAACGTTACTAATTATATT  
500 550  
CTCGGCTTCGCACCTTGGCTATCAACACCTGAGAGATACAGAGGCCGAGATGCCCAACCAT  
600  
GAAGCAATCACTAGACCAATCCAAGTGGCTCAGGGAGGCAGAAAACATCTTCGGGTACTAG  
650  
AAAACCTCGTGGACTCGAACCTAGAAAGAAAGTTAAAAACACAGTTGTCTATGGGAGAA  
700  
GACGTTCAAAGTCCAGGGATAGGAGAGCCCCCTTCACCCCAACGTGCGGGCTCCCCTCTCCCG  
750  
CGTAGTTCGAGCAGCCACAGAAAGATCTCCCTCGCCTAGGAAA 786

FIG.2

3/20

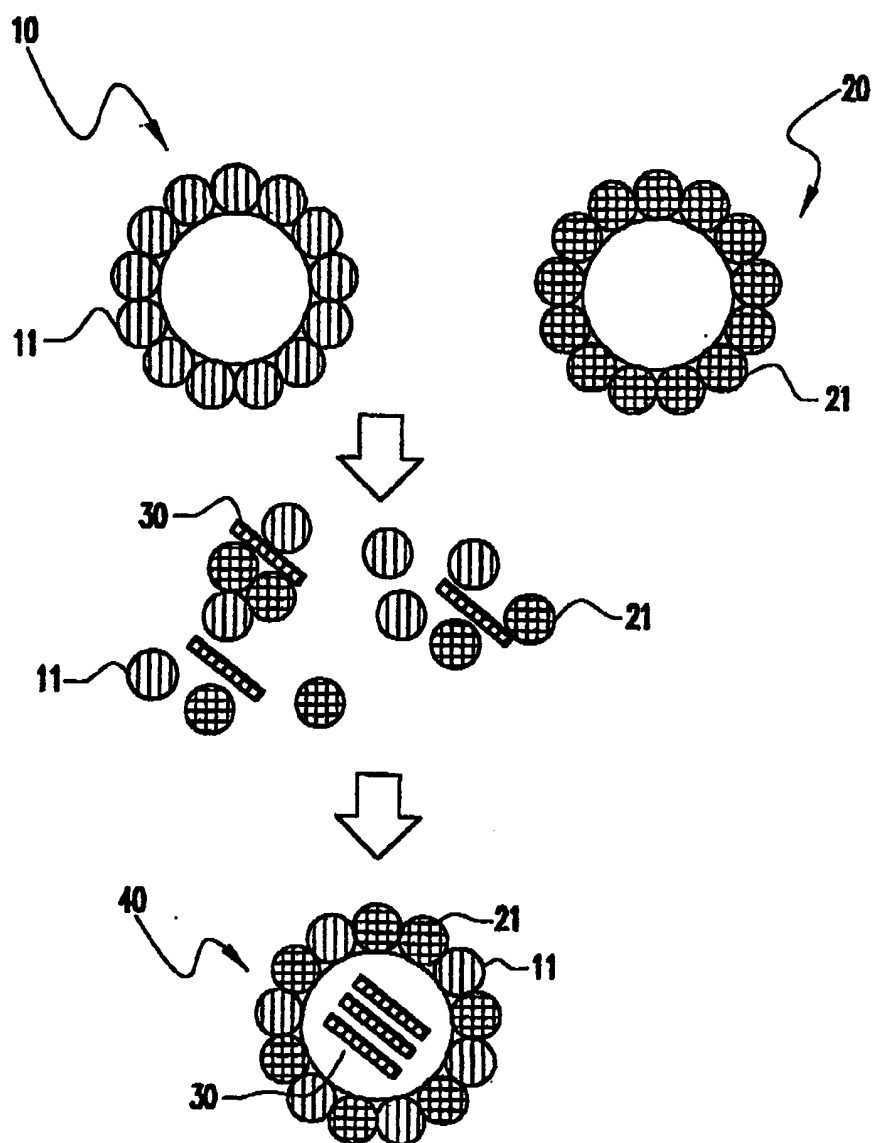
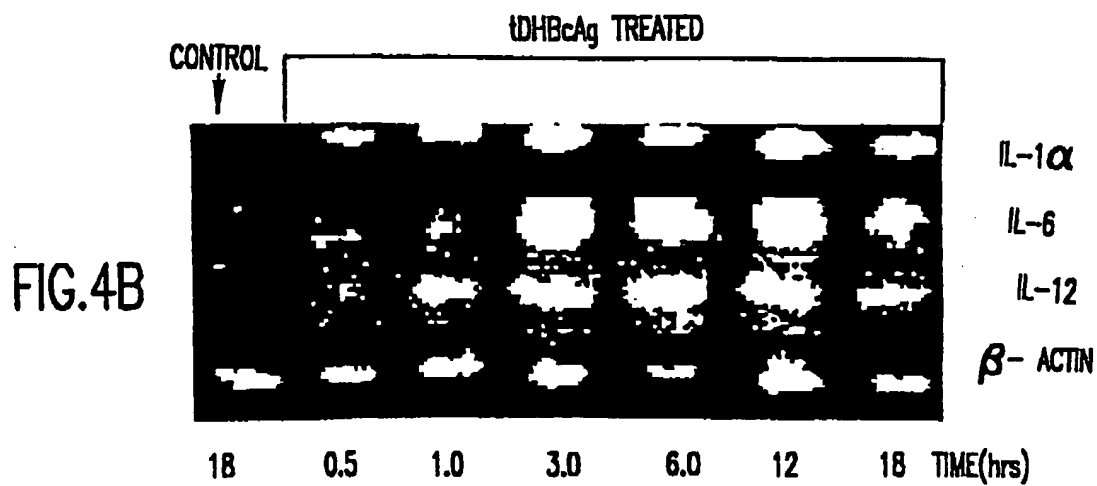
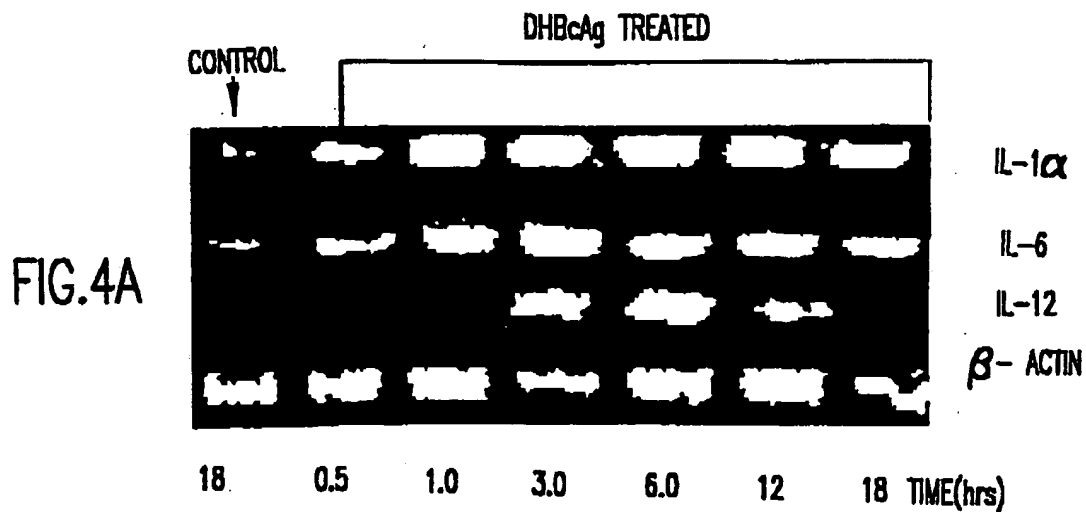


FIG.3

4/20



BEST AVAILABLE COPY

SUBSTITUTE SHEET (RULE 26)

5/20

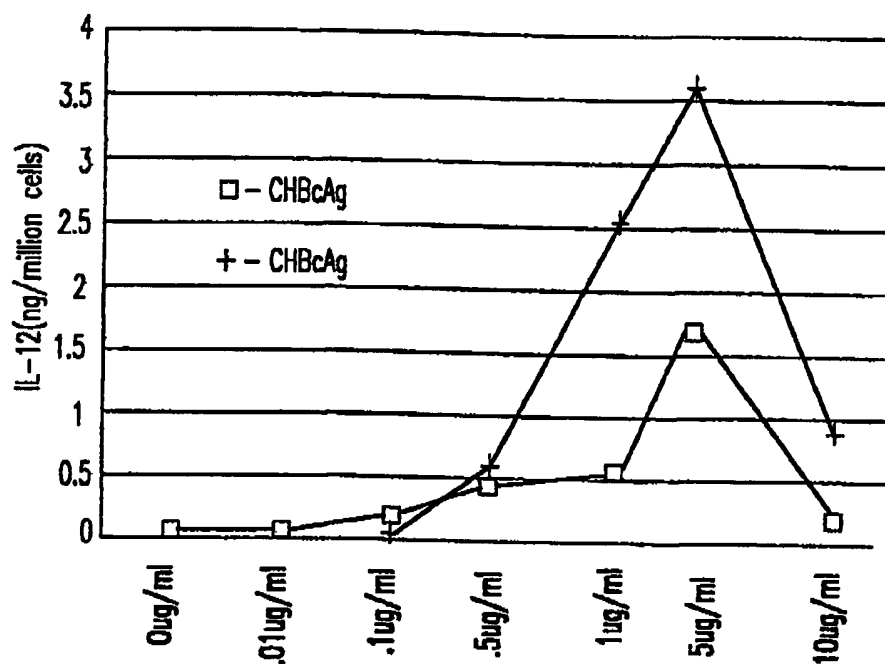


FIG. 5A

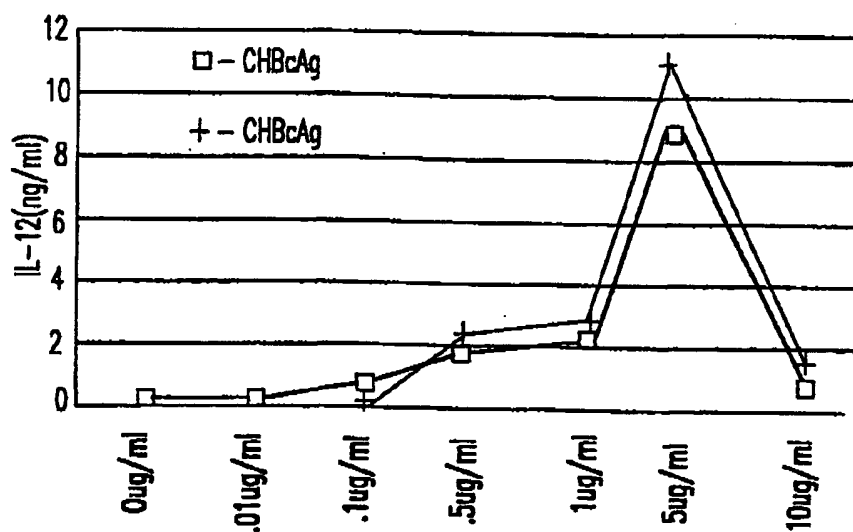


FIG. 5B



6/20

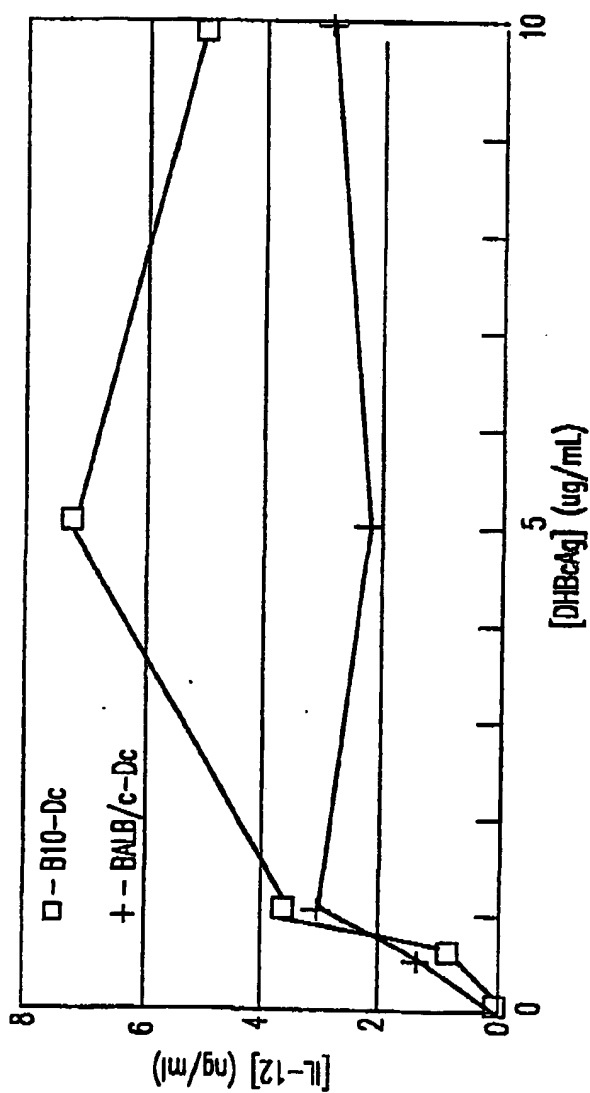


FIG.6

7/20

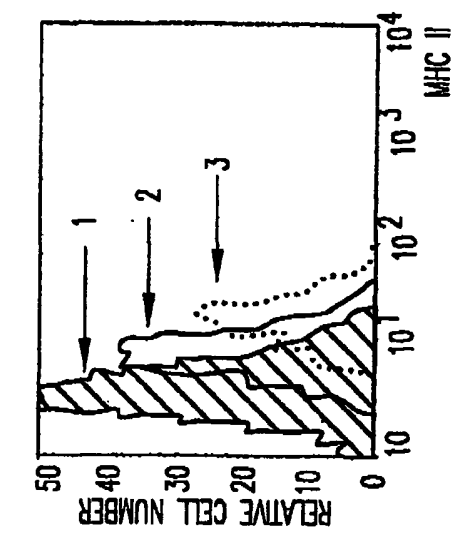


FIG. 7C

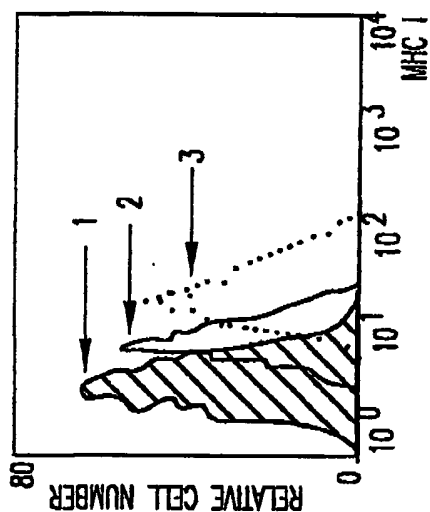


FIG. 7B

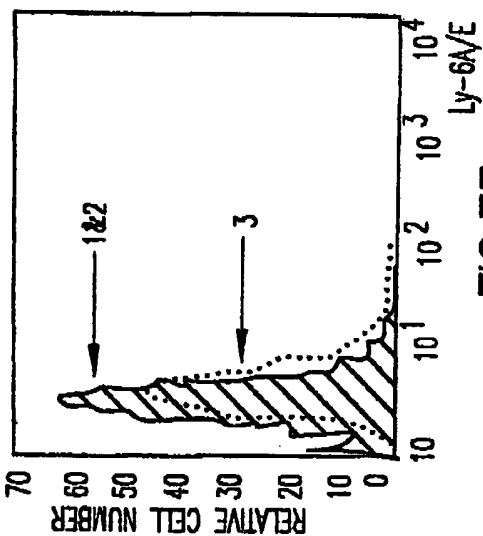


FIG. 7E

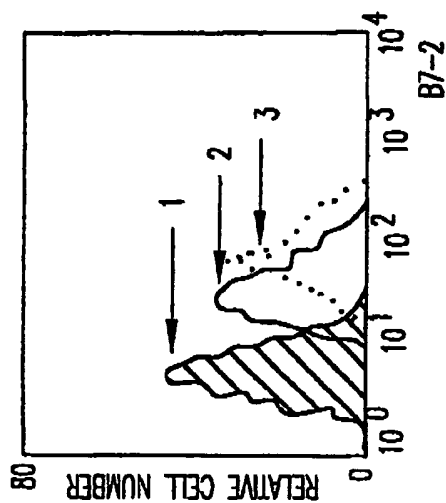


FIG. 7A

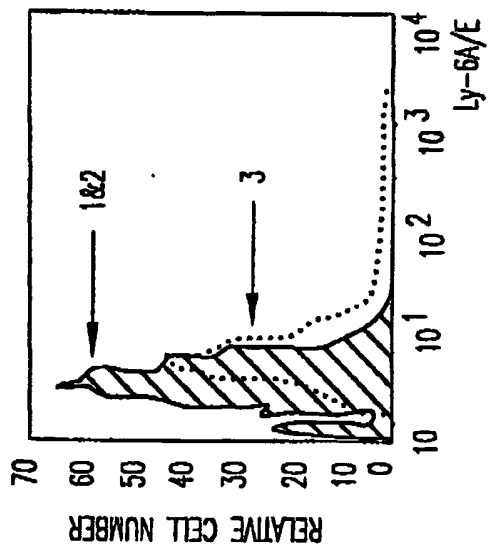


FIG. 7D

8/20

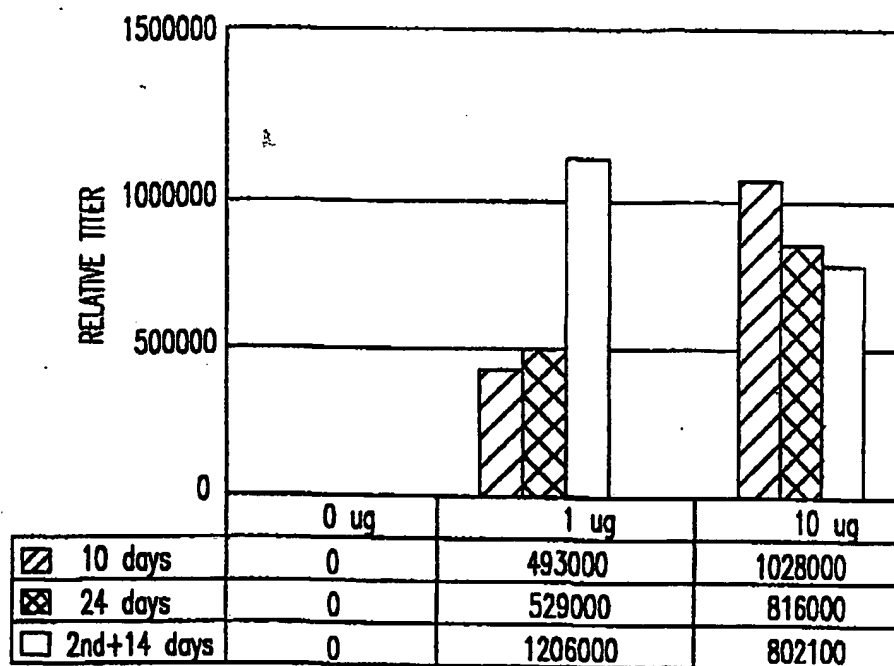


FIG. 8A

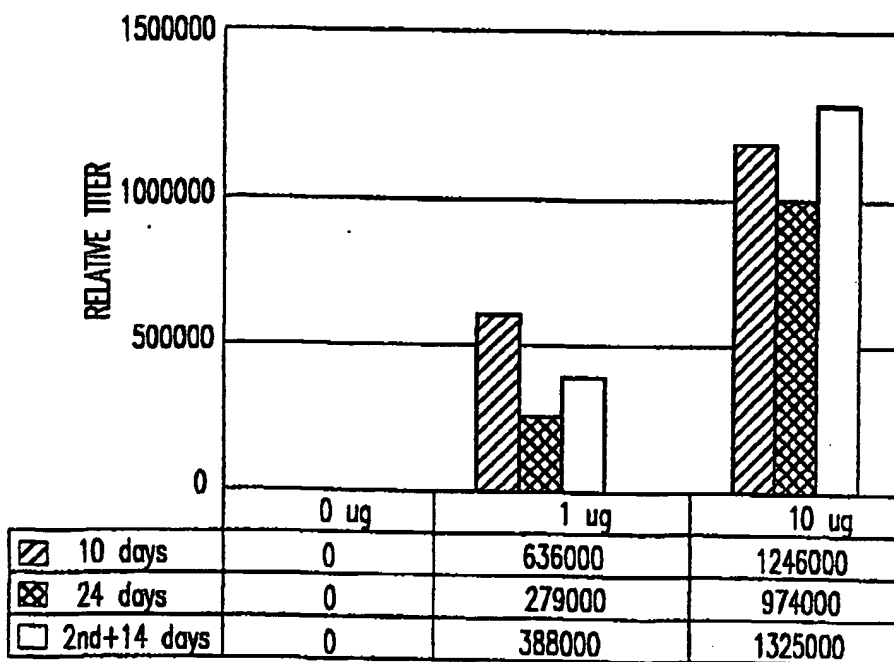


FIG. 8B

9/20

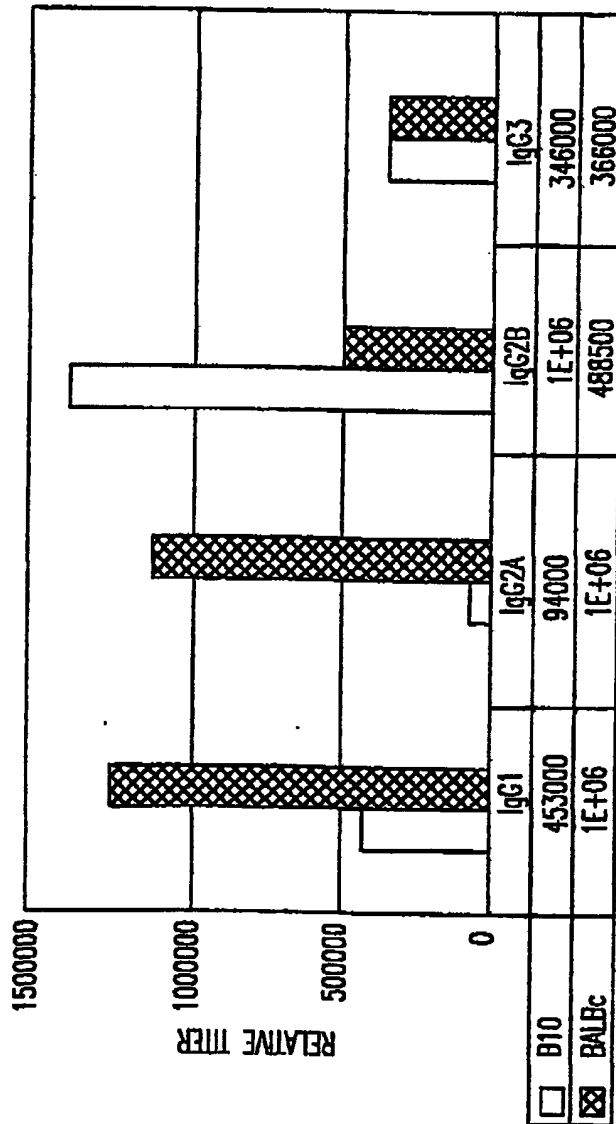


FIG.9

10/20

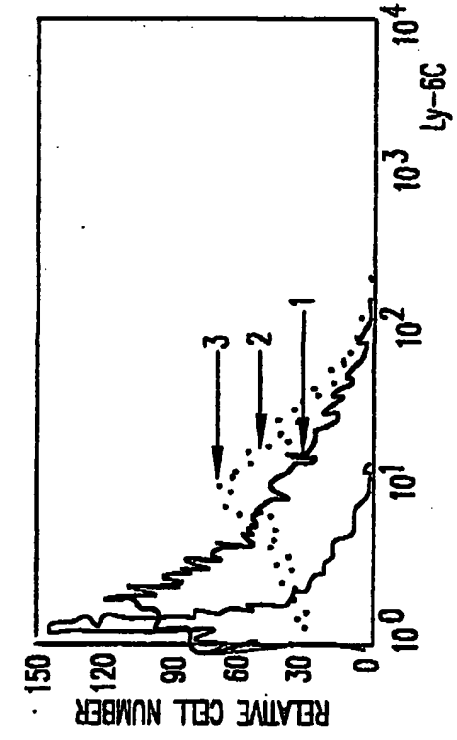


FIG. 10A

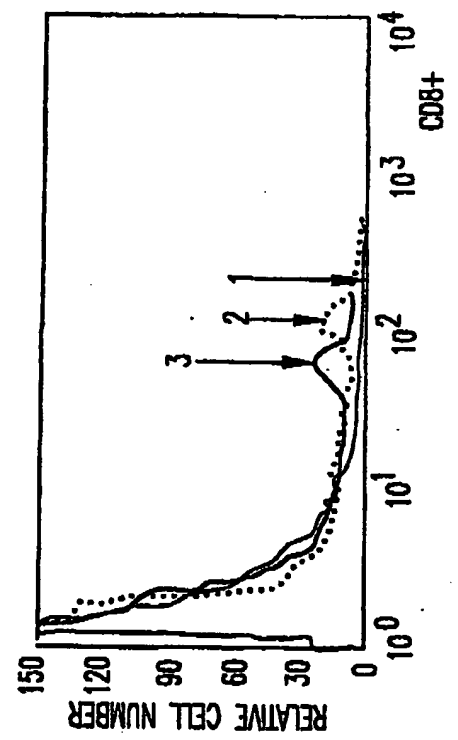


FIG. 10B

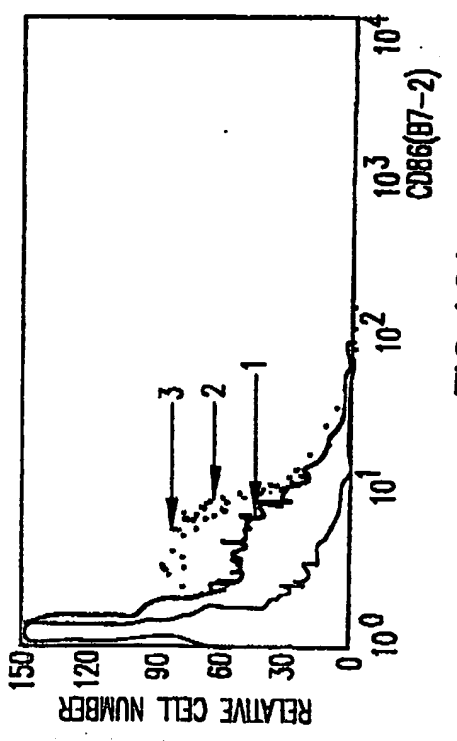


FIG. 10C

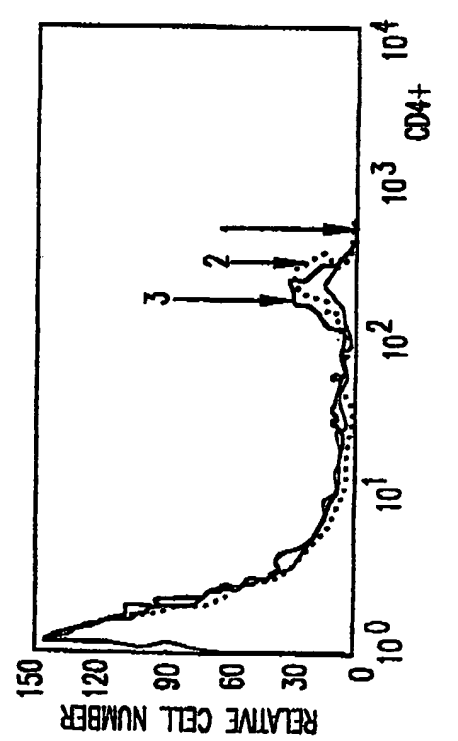


FIG. 10D

11/20

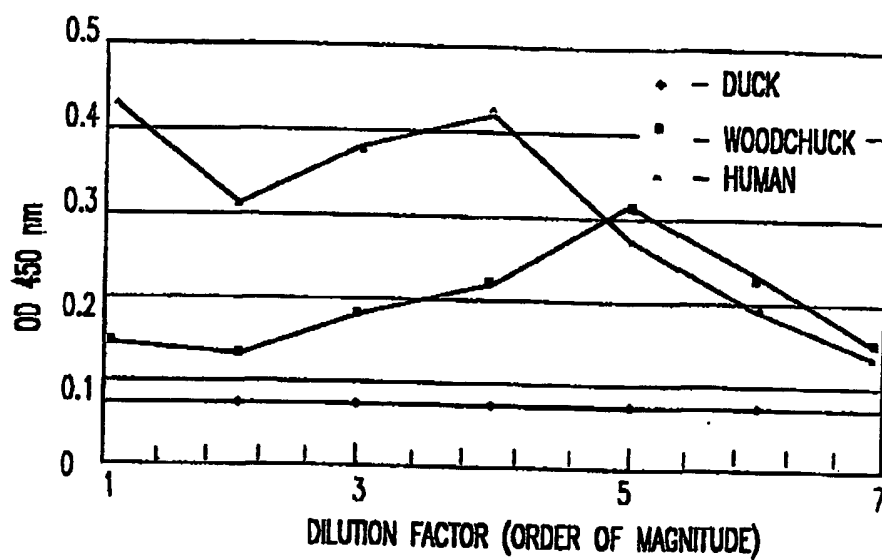


FIG. 11A

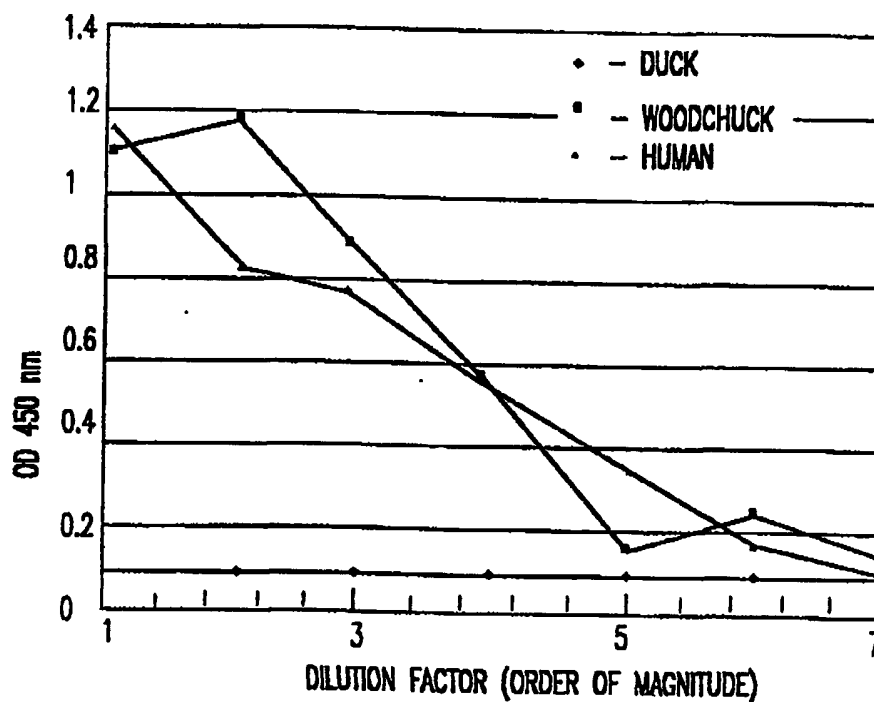


FIG. 11B

12/20

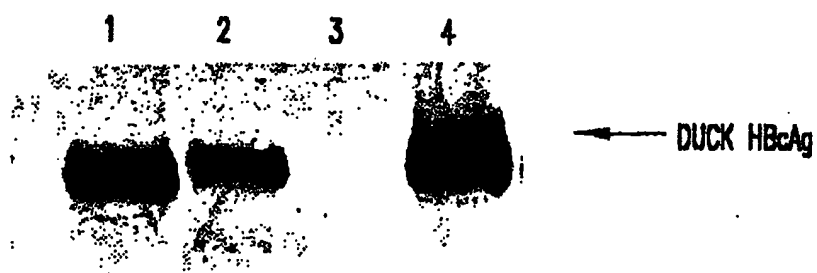


FIG.12

BEST AVAILABLE COPY

13/20

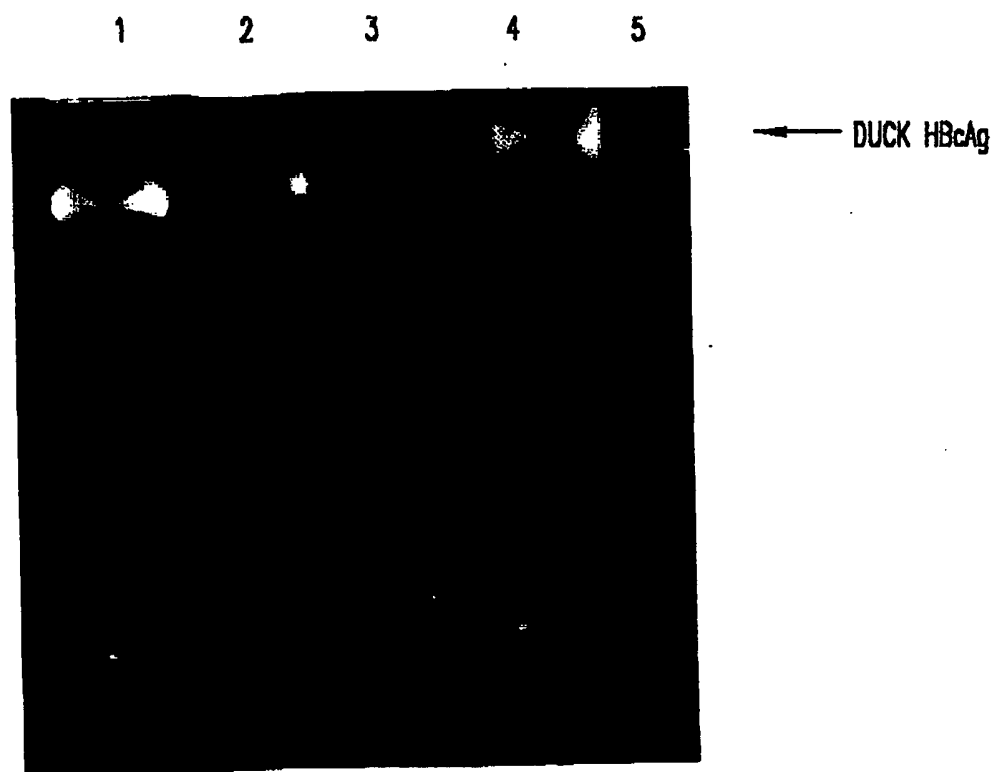


FIG.13

BEST AVAILABLE COPY



14/20

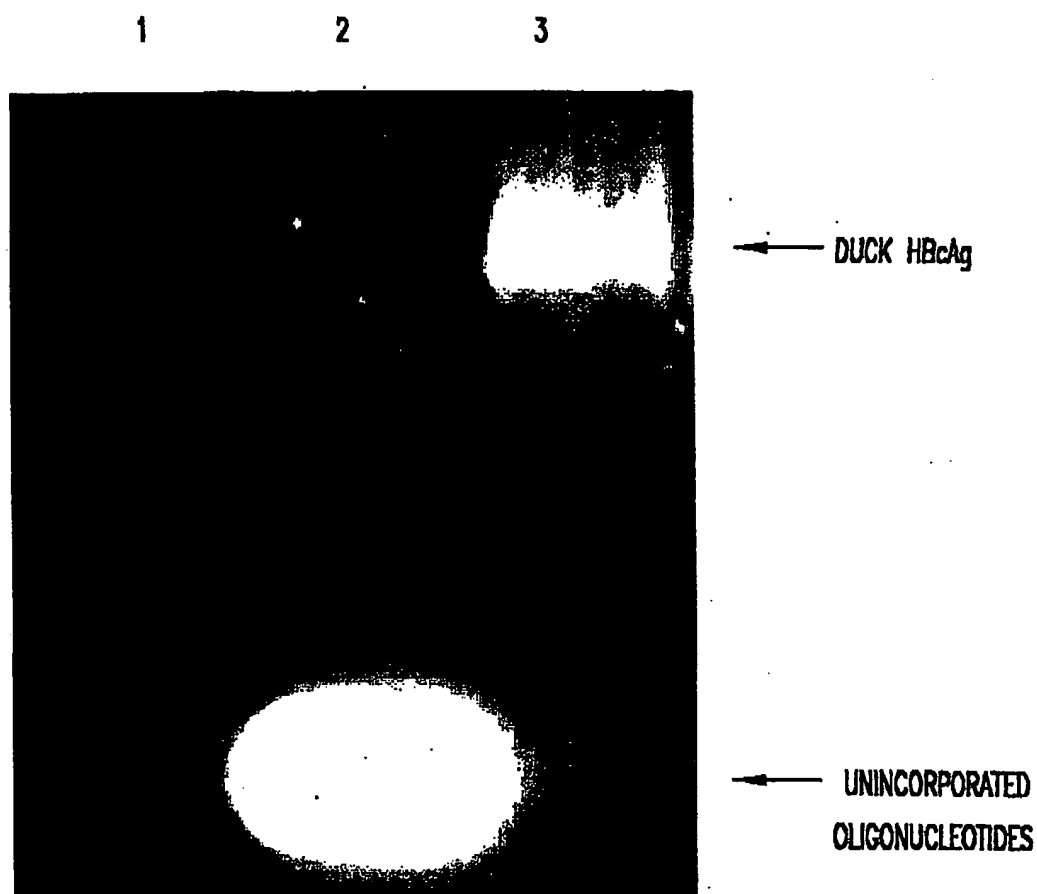


FIG.14

BEST AVAILABLE COPY

15/20

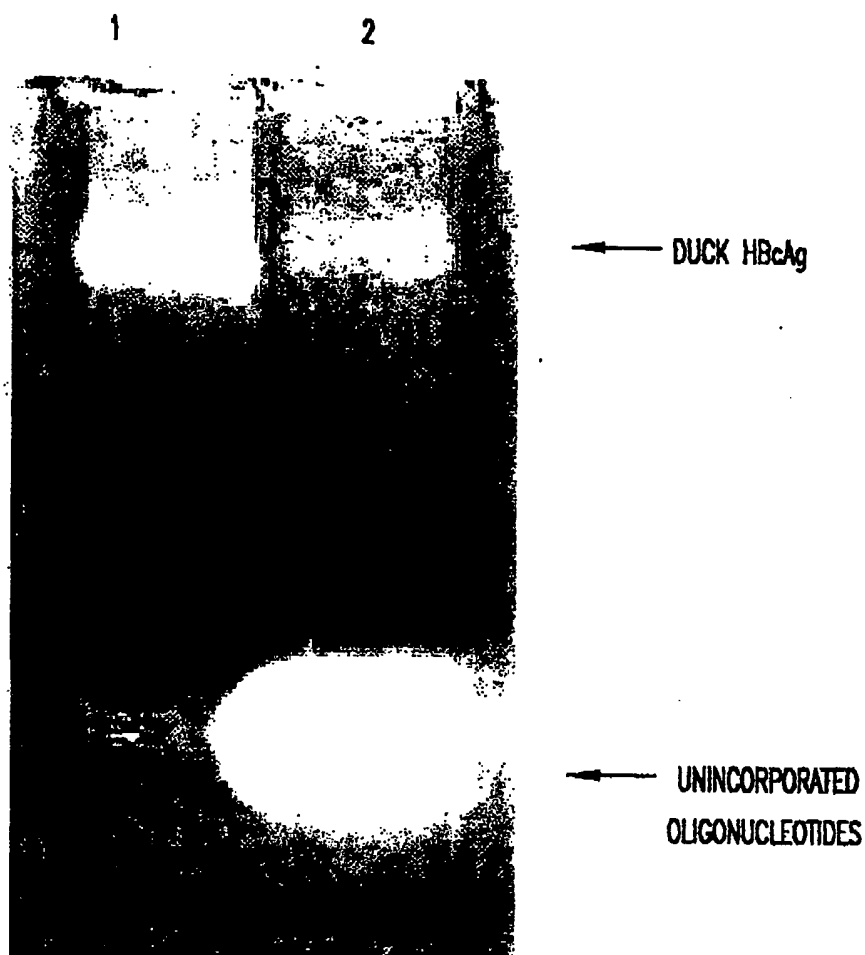


FIG.15

BEST AVAILABLE COPY

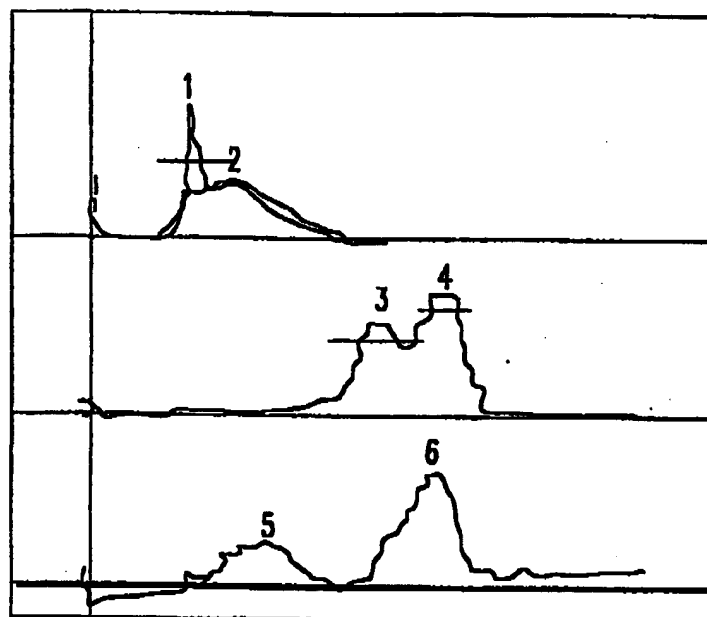
*SUBSTITUTE SHEET (RULE 26)*

16/20

FIG.16A

FIG.16B

FIG.16C



17/20

<sup>1</sup>MDINASRALANVYDLPDD<sup>25</sup>FFPKIDDLVRDAKDALEPYWR  
<sup>50</sup>SDSIKKHVLIA<sup>75</sup>THFVDLIEDEFWQTTQGMHEIAEALRAVI  
<sup>100</sup>PPTTPVPAGYLIQHEEAE<sup>125</sup>EIPLGDLFKHQEERIVSFQP  
<sup>150</sup>DYPITARIHAHLKAYAKINEESLDRARRLLWWHYNCLLW  
<sup>175</sup>GEANVTNYISR<sup>200</sup>LR<sup>225</sup>TWLSTPERYGRDAPTIEATRPIQV  
AQQGRKTSSGTRKPRGLEPRRRKVKTTVVYGRRRSKSRD  
<sup>239</sup>RRAPS

FIG.17

18/20

1 ATGGATATCAATGCTTCTAGAGCCCTTAGCCAATGTTTATGATTTGCCAGATGATTCTTCCC 50  
AAAATTGATGATCTTGTAAGGGATGCCAAGGATGCTTTAGAACCTTATTGGAGATCAGATT 100  
CAATAAGAAACATGTTTAAATTGCAACTCACTTTGTGGATCTTATTGAAGACTTCTGGCAA 150  
ACTACTCAGGGTATGCAATAGCTGAAGCCTTAAGAGCAGTTATACCACCTACTACAAC 200  
ACCAGTCCCGCAGGATATCTGATTTCAGCACGAAGAGGCTGAGGAGATTCCCTCTGGGAGATT 250  
TATTTAACATCAGGAAGAAAGGATAGTTAGTTTCCAACCGGATTATCCTATTACTGCACGA 300  
ATTTCATGCACACCTGAAAGCTTATGCAAGATTAAACGAGGAATCACTGGATAGGCTAGGAG 350  
ATTGCTTTGGTGGCATTACAAATTGTTTACTGTGGGAGAGCTAACGTTACTAATTATATTT 400  
CTCGGCTTCGCACCTTGGCTATCAACACCTGAGAGATACAGAGGCCGAGATGCCCCCAACCATT 450  
GAAGCAATCAGACCAATCCAAGTGGCTCAGGGAGGCAGAAAACATCTTCGGGTTACTAG 500  
AAAACCTCGTGACTCGAACCTAGAAGAAAGTTAAAACCCACAGTTGTCTATGGGAGAA 550  
GACGTTCAAAGTCCAGGGATAGGAGAGCCCTTCA 600  
718

FIG.18

19/20

1 MDINASRALANVYDLPDD<sup>25</sup>FFPKIDDLVRDAKDALEPYWR  
SDSIKKHVLIA<sup>50</sup>THFVDLIEDFWQTTQGMHEIAEALRAVI<sup>75</sup>  
PPTTPVPAGYLIQHEEAEEI<sup>100</sup>PLGDLFKHQEERIVSFQP  
DYPITARIHAHLKAYAKINEESLDRARRLLWWHYNCLLW<sup>125</sup><sup>150</sup>  
GEANVTNYISR<sup>175</sup>LTWLSTPERYGRDAPTIEATRPIQV  
AQGRKTSSG<sup>200</sup>TRKPRGLEP<sup>214</sup>

FIG.19

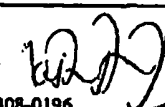
20/20

1 ATGGATATCAATGCTTCTAGAGCCTTAGCCAATGTTTATGATTTGCCAGATGATTTCTTCCC 50  
AAAATTGATGATCTTGTAAGGGATGCGAAGGATGCTTTAGAACCTTATTGGAGATCAGATT 100  
CAATAAGAAACATGTTTTTAATTGCAACTCAGTTTGTGGATCTTATTGAAGACTTCTGGCAA 150  
ACTACTCAGGGTATGCATGAAATAGCTGAAGCCTTAAGAGCAGTTATACCACCTACTACAAC 200  
250 ACCAGTCCCGCAGGATATCTGATTCAGCACGAAGAGGCTGAGGAGATTCCCTCTGGGAGATT 300  
TATTTAAACATCAGGAAGGATAGTTAGTTTCCAAACCGGATTATCCTATTACTGCACGA 350  
ATTGATGCACACCTGAAAGCTTATGCAAAAGATTAAACGAGGAATCACTGGATAGGGTAGGAG 400  
ATTGCTTTGGTGGCATTAACAATTGTTTACTGTGGGAGAGCTAACGTTACTAATTATATTT 450  
500 CTCGGCTTCGCACTTGGCTATCAACACCTGAGAGATACAGAGGCCGAGATGCCCAACCAT 550  
GAAGCAATCACTAGACCAATCCAAGTGGCTCAGGGAGGCAGAAACATCTTCGGGTACTAG 600  
AAAACCTCGTGGACTCGAACCT 642

FIG.20

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/02413

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(7) : C12N 15/11; C07K 14/00 US CL : 514/44; 536/23.1; 530/350; 435/320.1; 424/135.1 According to International Patent Classification (IPC) or to both national classification and IPC														
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 514/44; 536/23.1; 530/350; 435/320.1; 424/135.1 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched NONE Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) CAPLUS, MEDLINE, WPIDS, WEST, STN. search terms: nucleocapsid, duck hepatitis B, monomer, particle, mosaic, capsid, hapten, Hepatitis B virus, nucleocapsid proteins														
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>														
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.												
X	BRINGAS, R. Folding and assembly of hepatitis b virus core protein: A new model proposal. Journal of Structural Biology. 1997, Vol. 118, No. 3, pages 189-196, whole document	1-13												
A, E	US 6,025,341 A (WANDS et al) 15 February 2000, whole document.	1-23												
Y	MILICH et al. The Hepatitis nucleocapsid as a vaccine carrier moiety. Annals of New York Academy of Sciences. 1995, Vol. 754, pages 187-201, whole document.	1-23												
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.														
<table border="0"> <tr> <td colspan="2"> <b>Special categories of cited documents:</b> </td> </tr> <tr> <td>*A* document defining the general state of the art which is not considered to be of particular relevance</td> <td>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>*B* earlier document published on or after the international filing date</td> <td>*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>*L* document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>*O* document referring to an oral disclosure, use, exhibition or other means</td> <td></td> </tr> <tr> <td>*P* document published prior to the international filing date but later than the priority date claimed</td> <td>*A* document member of the same patent family</td> </tr> </table>			<b>Special categories of cited documents:</b>		*A* document defining the general state of the art which is not considered to be of particular relevance	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	*B* earlier document published on or after the international filing date	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	*L* document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	*O* document referring to an oral disclosure, use, exhibition or other means		*P* document published prior to the international filing date but later than the priority date claimed	*A* document member of the same patent family
<b>Special categories of cited documents:</b>														
*A* document defining the general state of the art which is not considered to be of particular relevance	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention													
*B* earlier document published on or after the international filing date	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone													
*L* document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art													
*O* document referring to an oral disclosure, use, exhibition or other means														
*P* document published prior to the international filing date but later than the priority date claimed	*A* document member of the same patent family													
Date of the actual completion of the international search 02 JUNE 2000		Date of mailing of the international search report 27 JUN 2000												
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer PADMA BASKAR  Telephone No. (703) 308-0196												



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/02413

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SCHODEL et al. Structure of Hepatitis B Virus Core and e-Antigen. A single precore amino acid prevents nucleocapsid assembly. The Journal of Biological Chemistry. 15 January 1993, Vol. 268, No. 2, pages 1332-1337, whole document.	1-23
Y	SCHODEL et al. Immunization With Hybrid Hepatitis B Virus Core Particles Carrying Circumsporozoite Antigen Epitopes protects Mice Against <i>Plasmodium yoelii</i> Challenge. Behring Inst. Mitt. 1997, Vol. 98, pages 114-119, whole document.	1-23

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/02413

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐

The additional search fees were accompanied by the applicant's protest.

☒

No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US00/02413

### BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

Group I, claims 1-20, drawn to a composition (claims 1-13) comprised of plurality of nucleocapsid protein from duck hepatitis B virus, method of making (claims 17-20) and method of use (claims 14-16) of delivering nucleic acids to a subject in need.

Group II, claims 21-23, drawn to another method of use for inducing an immunogenic response.

The inventions listed as Groups I and II do not relate to single inventive concept under PCT Rule 13.1 because, under PCT

Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Group I is directed to a composition comprised of a plurality of nucleocapsid protein monomers, the primary sequences of which are derived from duck hepatitis B virus and method for producing the nucleocapsid protein monomer particle and using the same to deliver nucleic acids to a subject in need, which is the first product, first method of making and first method of using the product. The special technical feature is the nucleocapsid protein monomer and said particle is assembled as an intrinsic mosaic. Group II is drawn to another method of use having different goals, method steps and starting materials, which do not require each other for their practice and do not share the same or a corresponding technical feature. Note that PCT Rule 13 does not provide for multiple products or methods within a single application. Since the special technical feature of the Group I invention is not present in the Group II claims, and the special technical features of the Group II inventions are not present in the Group I claims, unity of invention is lacking.

**THIS PAGE BLANK (USPTO)**